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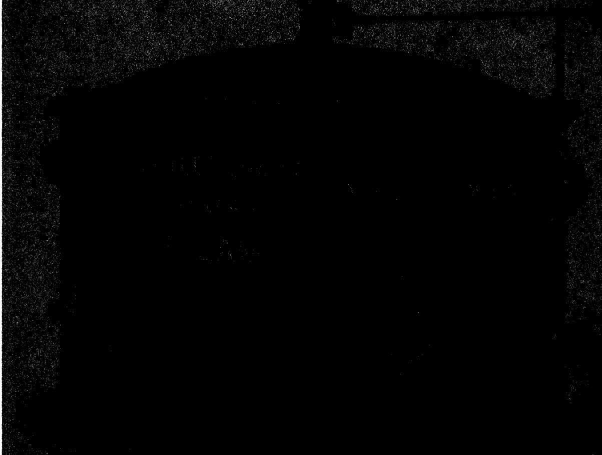

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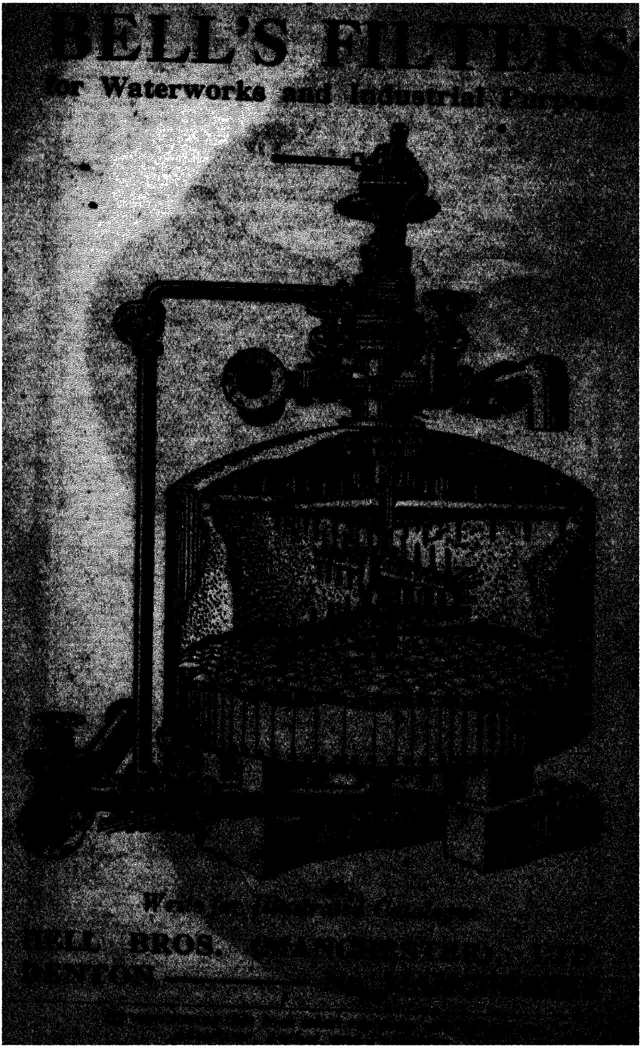

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THE FILTRATION OF LIQUIDS AND GASES

FOR

THOSE CONCERNED WITH WATER SUPPLY,
VENTILATION, AND PUBLIC HEALTH; CHEMISTS,
MECHANICAL ENGINEERS, AND OTHERS

BY

T. ROLAND WOLLASTON

MEMBER OF THE INSTITUTION OF MECHANICAL ENGINEERS

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PREFACE

THE subject of Filtration is a large one, in which engineer, chemist, and biologist are equally concerned—each depending for his progress upon assistance rendered by the others. In this volume the author offers an elementary introduction to the work of these specialists and he has endeavoured to provide a treatise which will be easily readable, sound in principle within its limits, and up to date.

In many branches of industrial filtration the author has personal experience; in other branches of the art he claims only the knowledge of an interested observer, but his manuscript has been read and revised by friends highly skilled in their respective departments. In this connection he respectfully acknowledges the kind assistance received from John Allen, F.I.C., E. Ardern, D.Sc., F. E. Barclay, D.Sc., Ph.D., S. E. Melling, F.I.C., and F. H. Terleski; also, his indebtedness to Mr. Livingstone Whyte for the loan of a valuable collection of papers relating to Filtration; to his son Geoffrey L. Wollaston for preparing line illustrations, and to various firms mentioned in the text for certain blocks and much useful information.

T. ROLAND WOLLASTON.

THE ENGINEERS' CLUB,
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FILTRATION

CHAPTER I

CHEMICAL PRECIPITATION, COAGULATION, AND SEDIMENTATION

THE most common and best known application of chemical precipitation for public utility is the softening of hard water. Through this channel the author has chiefly derived experience in filtration and, though at first glance not directly to be classified as filtration but rather as preliminary thereto, it offers so excellent a line of approach that a few introductory notes thereon will help towards a correct appreciation of the main subject.

Hard and Soft Water. Rain water is absolutely pure at its origin, but, in falling in thickly populated industrial centres, it becomes more or less contaminated before it reaches the earth. Thereafter it absorbs animal, vegetable, and mineral matter by percolation and contact so that, as we get it from rivers, lakes, wells, or the like for domestic or industrial purposes, it is always impure to a greater or less degree. Hardness of water, its property of neutralizing soap, is known to everyone, and is due to dissolved salts of lime and magnesia—carbonates, sulphates, nitrates, and chlorides. An excellent illustration of this is to be found in the natural waters of the Thames watershed which, in percolating through the chalk formations, take into solution considerable quantities of lime and magnesia salts.

The following is a typical analysis of water supplied to the mains by one of the London Water Departments—

	Grains per gallon.
Silica	0·26
Alumina	0·14
Carbonate of lime . . .	12·70
Sulphate of limo	1·60
Nitrate of lime	1·00
Nitrate of magnesia . . .	1·28
Chloride of sodium . . .	2·02
Total	19·00

A water of this kind may be perfectly clear, sparkling, and wholesome for drinking and domestic purposes, but it is not pleasant to use for ablutions; it causes great waste of soap in the laundry, and leaves hard chalk-like deposits in steam boilers, kettles, and the like.

As an illustration of variation due to geological differences in the collecting ground the following analysis of Manchester Town's main water, as derived from the Woodhead Reservoirs, is given—

	Grains per gallon.
Silica	0·30
Carbonate of lime	1·70
Sulphate of magnesia . . .	1·66
Chloride of sodium . . .	0·91
Total	4·57

Few public-supply waters are lower than this in mineral impurities and hardness.

Water Softening. Waters of the former and indeed of most natures may be softened by the addition of small quantities of lime water and carbonate of soda. Carbonates of lime and magnesia (or, as they exist in hard water, the soluble bicarbonates) take up added lime to combine with their carbonic acid and to become insoluble carbonates. The typical reactions are—

I. TREATMENT FOR TEMPORARY HARDNESS

Bicarbonate of Calcium	+	*Caustic Lime*	=	*Carbonate of Lime*	+	*Water*
$CaH_2(CO_3)_2$ Soluble	+	CaO Soluble	=	$2\ CaCO_3$ Insoluble	+	H_2O

II. TREATMENT FOR PERMANENT HARDNESS

Sulphate of Calcium.	+	*Carbonate of Soda.*	=	*Carbonate of Lime.*	+	*Sulphate of Soda.*
$CaSO_4$ Soluble	+	Na_2CO_3 Soluble	=	$CaCO_3$ Insoluble	+	Na_2SO_4 Soluble

The reactions with magnesium salts are similar.

In the first of these reactions (for what is called *temporary hardness**) the carbonate of lime is thrown from solution into suspension and can be seen as minute particles floating in the water, giving it a milky appearance. In so far as the reaction may be carried the bicarbonates are eliminated and nothing is left behind to replace them. The only bar to complete elimination is the fact that the carbonates of lime and magnesia are slightly soluble.

---

* "*Temporary Hardness*" is due to bi-carbonates of calcium and magnesium in solution which are precipitated by boiling at atmospheric pressure, or in some cases at lower temperatures.

In the second reaction (for what is called *permanent hardness**) it will be noted that a new salt, sulphate of soda, is left in solution, but this is harmless for almost every service. The matter rendered insoluble is again carbonate of lime or carbonate of magnesia.

The typical chemical formulae given above are in the form appearing in a report presented by Mr. C. E. Stromeyer, Chief Engineer to the Manchester Steam Users' Association, to his Directors in 1903. They are also to be found in that gentleman's paper read before the Institution of Mechanical Engineers.† The Author knows of no publication in which the principles of water softening are set forth more clearly and concisely than in that paper, and readers seeking further information upon the subject are advised to obtain a copy.

Chemical Precipitation. The student who has no experience of chemical precipitation is advised to study it by a simple experiment. If he should have available a hard water (for example London water) let him first make a solution of clear lime water in the following manner: Obtain a piece of lump lime about as large as a marble, put it into an ordinary bottle and add a few drops of water so as to moisten but not to cover it. In a few minutes, if the lime be of good quality, it will fall to powder, evolving heat. When the lime has fallen completely, add water until the bottle is three-fourths full, cork, shake well, and put away for a few hours. There is thus obtained clear saturated lime water, with an excess of lime lying at the bottom.

---

* "*Permanent hardness*" is due to sulphates, nitrates, and chlorides of calcium and magnesium in solution, these being precipitated only at comparatively high temperatures and pressures.

† *Proceedings* No. 4, Oct., 1903.

Now two-thirds fill an ordinary tumbler or clear glass bottle with the hard water, add to it about one-fifth its volume of the clear lime-water, stir well, and observe. Probably the whole will become opalescent or milky. If placed in a good light and observed carefully it will be seen that in a few minutes the solid matter aggregates together into small but easily seen floating particles, which are slightly heavier than water. In course of time, may be in ten minutes, may be in an hour, all these minute particles will have gravitated to the bottom as a white sludge, and the supernatant water will be clear and bright and (if the arbitrary amount of lime water added happen to be correct) almost free from temporary hardness.

An experiment, equally valuable for study, and perhaps somewhat easier to carry out, is to make a strong solution of common salt in the tumbler and another of silver nitrate in the small bottle. A few drops of the latter added in the former will react, causing milkiness, due to insoluble silver-chloride, which will clear in the same manner.

Natural Sedimentation. The part played by natural sedimentation in modern filtration does not seem to be appreciated sufficiently by many authors who have written upon the subject. The author, while engaged upon this manuscript, quite accidentally came across a paper read by Dr. John S. Owens before the Royal Geographical Society in 1911,* describing fully a most interesting research upon the subject. His investigation was directed mainly towards the behaviour of suspended solids in rivers and streams, and the effects in silting up estuaries and the like, but the experiments with different materials and the tabulated and graphical representations thereof cannot fail to assist those interested in filtration.

In the examples given in the preceding section, the precipitates—calcium carbonate and silver chloride—are of fairly high specific gravity and will, in course of time, settle down to the bottom of the vessel, but this is not the case with all suspended matter with which one may have to deal. River water, for example, is sometimes found to carry clay and mud so finely divided and light that, if left stagnant in a vessel for days, it will not precipitate. A common example in industrial practice is the softening or purification of water from the condensers of steam engines in which there is oil in emulsified condition.

The experiment in softening, previously described, carried out upon a hard water of this oily nature, is one deserving careful study, as it is typical of many phenomena occurring in practical filtration. The carbonate of lime precipitate will appear as in the case of the clear water, but there is strong mutual attraction between the mineral particles and the minute globules of oil which therefore become attached to each other. Often this amalgamation produces a combination which is lighter than water and which, instead of falling to the bottom of the vessel, rises and forms a scum on the surface. If in any particular problem of filtration such behaviour can be foreseen by experiment it becomes of great assistance in designing plant.

---

* *Proceedings*, Vol. xxxvii, No. 1.

Coagulation. The obtaining of a precipitate or filtrate of tractable nature, or, to use the term commonly employed, *coagulation*, is of vital importance as a preliminary step towards satisfactory filtration in many instances of public or industrial supply, and one may advantageously explain at this stage the various means adopted.

(1) In the case of a hard or softened water carrying very finely divided and light mineral matter in suspension the addition of a precipitant, for example alumino-ferric, sulphate of alumina, or copperas, with sufficient alkali in the form of lime or carbonate of soda to react with it, will result in the formation of a heavy and flocculent precipitate which, during sedimentation, carries down the lighter matter.

(2) In distilled surface-condenser water containing oil or grease in emulsion, so finely divided as

to be beyond the power of any purely mechanical filter to remove, treatment with similar precipitants will form an artificial precipitate which, attracting and amalgamating with the oil globules, becomes readily filterable.

(3) In water from wells, streams, or lakes, which requires filtration for public domestic use, there is found highly deleterious matter of animal, vegetable, and mineral nature so minutely divided as to defy filtration by any purely mechanical straining action. Such matter may be coagulated by slight additions of such reagents as are mentioned above so as to be capable of interception in passing through the interstices of, say, a bed of sand, or as is more general, to form a semi-impervious film upon the surface of the sand—the extracted matter thus becoming the true filtrant.

(4) Matter of the lightest and most finely divided nature, having once precipitated as a sludge, generally acquires increased density so that, if agitated or blown up into suspension again by steam or compressed air, it will deposit more rapidly. This effect increases if the operation be repeated, and, if several volumes of water be successively treated in a given vessel, the clarified water being decanted off but the sludge allowed to accumulate, large volumes of old sludge being ultimately blown or stirred into newly treated water lead to very rapid precipitation of the whole. The effect is indeed analogous to a moving filter-bed traversing stagnant water and dragging down from it the lighter suspended matter. This action

is utilized very beautifully in the well-known Archbutt-Deeley process of water softening, and again in the highly promising " activated sludge " system of sewage purification.

The Activated Sludge Process. In this process successive volumes of sewage are allowed to deposit their suspended solids in open tanks until a considerable depth of sludge has accumulated. New sewage is run in and compressed air is introduced at the bottom through porous tiles, blowing up and keeping in suspension the old sludge and maintaining the necessary conditions of aeration. When the initial clotting effect is completed and the bio-chemical agencies have played their part, it is found not only that the old and new suspended matter settle very rapidly but also that a very considerable degree of chemical and biological purification has taken place without the addition of any reagents. The sludge, as it accumulates in excess of requirements, is drawn off and, when de-watered and dried, forms a most valuable nitrogenous fertilizer uncontaminated with deleterious chemicals or excessive grease.

CHAPTER II

PHYSICAL ACTION OF FILTERS

THE words "filter" and "filtration," like many other words in applied science, are used somewhat slackly, and convey different ideas dependent upon the nature of the duty of the moment.

Reference to a dictionary discloses the definition "FILTER, (v.) *To cleanse from impurities by straining.*" This perhaps correctly conveys the layman's conception. It implies that the 4-inch grating fitted at the intake of a hydro-electric station to retain chunks of wood and like detritus, is a filter; so is the fine muslin or wire gauze used in the kitchen. The engineer and chemist will agree, but will prefer to describe such media as strainers or sieves. To them, filtration means, in many of its applications, a great deal more than mere straining or sieving.

In Chapter I, we have endeavoured to outline briefly and generally the behaviour of suspended matter in water; to show how, in clarification, much depends upon the physical nature and density of the floating particles. We have stated that, in softening water in a tumbler or beaker, the period of sedimentation may be from ten minutes to an hour. Some suspended matter met with in practice is so finely divided and so nearly equal in specific gravity to the liquid in which it is suspended, that it will never precipitate.

The word "colloid" (another word which has lost its original meaning and is often used slackly) comes near to conveying the correct conception of this class of matter.

Filtration by Subsidence. Let us consider what happens in an ordinary sedimentation tank (Fig. 1). Water carrying suspended matter enters this long tank (of large cross sectional area) at A.

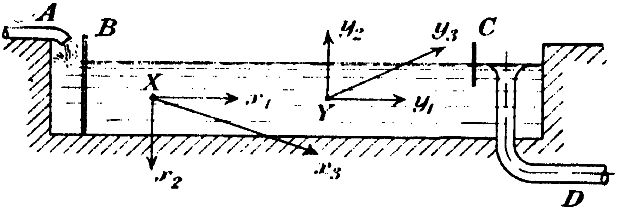

FIG. 1.—ILLUSTRATING ACTION OF SEDIMENTATION TANK.

At B there is a diaphragm, lattice, or other device to act as a means of distribution and of destroying the effects of any currents or eddies set up by the inflow, so that there is a steady and very slow flow, approximately horizontally, between B and C. The surface-intercepting diaphragm at C prevents scum from getting access to the outlet pipe D.

A particle of suspended matter X, heavier than water, is influenced by two forces, the momentum of flow x_1, and gravity x_2, under which it will assume a course indicated by (say) x_3, settling down finally upon the bottom of the tank.

On the other hand, a particle, Y, lighter than water, will be influenced also by the momentum of flow y_1, but will wish to float in the direction, y_2, and will therefore move in the direction, y_3, and appear finally as scum on the surface of the water.

It is obvious that, if there be a difference in specific gravity and if the current velocity be sufficiently low, we can thus eliminate matter from suspension in a liquid. It is also obvious that, the shallower the tank (always assuming the velocity of current is not increased) the earlier will the particle reach the bottom or the surface. By this line of reasoning we reach Wanklyn's Subsidence Filter, a simple and beautiful conception upon which, in principle, most modern filters may be considered as based, and which has inspired almost innumerable inventors of apparatus for accelerating the clarification of liquids. It is illustrated diagrammatically in Fig. 2, and is thus described in Wanklyn's own words :

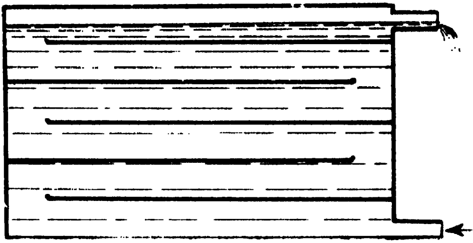

FIG. 2.—WANKLYN'S SUBSIDENCE FILTER.

> "When softening water we obtain a precipitate of finely divided carbonate of lime. If this operation be conducted in large glass vessels (three to four gallons) we

> can watch this process of depositing the precipitate. If we do so, we shall observe that the first sign of clearing takes place at the top, a layer of quite clear water making its appearance, and gradually extending downwards. If we ask how this water has become clear, the only answer that can be made is, that the precipitate has moved down to the layer of water beneath it, and thereby rendered that layer thick; for had the precipitate not descended into it, it would, like the top layer, have become clear. In the same way, the second layer, by its depositing, renders that beneath it turbid. If such a vessel of water took six hours to clear, we should expect that by dividing it into six layers by means of five diaphragms, equidistant from each other and from the top and bottom of the water, the water would clear in one sixth the time, or one hour. On making the experiment this is found to be the case. To test this matter more fully, what may be called a "subsidence-filter" was constructed. It consisted of a wooden box 12 ins. square and 20 ins. deep, containing 24 plates of sheet zinc ¾ in. apart. Each plate had six holes punched in it 1 in. in diameter. The holes were near to the side, and had their edges turned up a little; the plates were so arranged that the holes were not opposite each other. A small tap came from just below the lowest plate. Another box like this, but without plates, was also constructed. Both boxes were charged with freshly softened water, containing chalk suspended in it. The water took about eight hours to clear in the box without the plates, and was quite clear in the box with the plates at the end of about twenty-five minutes. This box of plates was next used as a filter, by sending a slow stream of water charged with suspended chalk through it. About eleven gallons an hour of quite clear water could be drawn off. If the speed was increased much beyond this, the water was no longer clear."

The obvious practical defect in this apparatus is the fact that accumulations of sludge will rapidly appear upon the shelves, and, at an early stage, it must be stopped for cleaning. Also it is only effective, as regards water, for precipitates having specific gravity higher than unity. By no stretch of imagination can such a filter be classed as a sieve or strainer.

Filtration by Straining. As a first example of filtration by sieving or straining, let us consider a piece of square wire mesh. If there be passed on to this a current of liquid containing suspended particles, any particle larger than the mesh will be retained. Some small proportion of smaller particles may also become wedged or interwoven and be retained, but the bulk of the smaller particles will pass through.

Another example may be taken, representing a deep strainer or sieve, let us say a box with open top packed with billiard balls (Fig. 3). Here again, between the balls, we have thoroughfares of symmetrical form, and any suspended matter smaller than these thoroughfares may be expected sooner or later to find its way through. One should not, however, lose sight of the fact that irregularly shaped or rough particles interfere and wedge together in such a strainer so that one might expect higher efficiency from the nest of billiard balls than from wire mesh with interstices equal to the minimum thoroughfare. The smooth surfaces of the balls will offer no appreciable surface obstruction

Filtration by Combined Straining and Subsidence. Let us now consider a filter in all respects similar to the nest of billiard balls except that lumps of broken coke or clinker of approximately the same size as billiard balls are substituted, (Fig. 4). Instead of smooth and symmetrical thoroughfares we now have irregular passages presenting ragged and sharp walls to the liquid, and instead of approximately constant velocity of current through all the interstices there are local eddies, periods of stagnation, and occasionally perhaps moments of acceleration. It is not difficult to grasp the analogy between the behaviour of turbid liquid passing through this and through the Wanklyn subsidence filter. Suspended matter larger than the interstices will be retained by sieve action. During short eddy and stagnation periods finely divided matter heavier than the liquid will fall; matter of light nature will rise. In either case it will come in contact with the sharp porous surface of the medium and, providing that the velocity of flow be regulated suitably, it will adhere thereto.

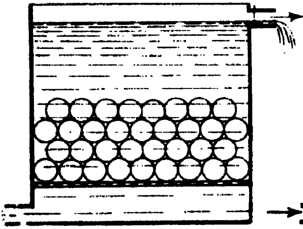

FIG. 3.—STRAINING FILTER PACKED WITH SMOOTH BALLS.

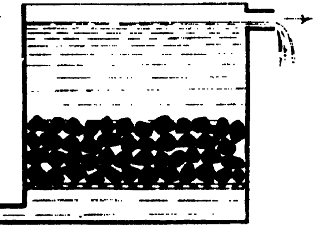

FIG. 4.—STRAINING FILTER PACKED WITH IRREGULAR POROUS PIECES.

This then may be regarded as a *true filter*. It is a sieve or strainer, and something more.

The efficiency will vary with the depth of bed and inversely with the velocity.

It has seemed well to describe this apparatus primarily in rough form, but, with the exercise of a little imagination the analogy between the billiard balls and coke on the one hand and smooth or sharp fine sand on the other is readily grasped, and may be carried still further to the porous cartridges of the charcoal or " Pasteur " domestic filters. All these media act first as strainers to intercept particles larger than their pores or interstices, and they subsequently provide innumerable minute chambers in which sedimentation of the microscopic particles may take place.

Deposited Matter Assists Filtration. Before concluding this section dealing with the purely mechanical and physical phenomena of the filter-bed we may briefly allude to another feature, often turned to good account. It may be taken as a general fact that old precipitate which has settled out from a liquid tends to attract and hold new and finer matter of the same nature. Also that slimy matter adhering to the walls of filtering media tends to assist in abstracting further matter. Generally, therefore, within reasonable limits of " building up " and velocity, a filter improves in efficiency as it continues in action, and the time limit of most filters is only reached when the head or pressure required to force the liquid through becomes excessive.

CHAPTER III

CHEMICAL AND BACTERIAL ACTION IN FILTRATION

Adsorption. So far we have regarded filters as having only mechanical or physical properties of clarifying liquids from suspended matter by sieving and internal sedimentation. Their applications extend, however, considerably beyond this point and, in many services, certain types are utilized to produce important chemical and biological changes. One of the filtrants best known in this connection is charcoal, particularly animal charcoal. This substance is used in many industries, notably the sugar industry, for removing organic discolouration, and is effective in eliminating bad tastes and odours, and many vegetable and mineral poisons. The action, which is by no means fully understood, is defined as " adsorptive " rather than chemical action. The ordinary sand filter has similar and useful action in removing ammonia and other dissolved organic impurities from water though not to the same degree as charcoal. This physical or adsorptive function must not be confused with the biological activity of " ripened " sand filters.

Bacteria and Vegetable Growths. The elimination or reduction of bacterial contamination is, of course, one of the most important functions of the large filtering plants used in connection with public water supply. It is a subject of wide importance and one on which a few notes must be given as a prelude to the description of various types of installation.

Bacteria are microscopic living organisms, and are of infinite variety. Some, for example the typhoid and cholera germs, are most dangerous to human life; others are useful in that they destroy harmful types. Broadly speaking, due to their very minute size, no ordinary medium can be expected to retain them by sieving. A well known authority states that clean sterilized sand has *no* power of germ interception.

The more harmful types of bacteria are frequently destroyed by prolonged storage of water before final filtration; it is said that three weeks storage of river water before filtration will ensure entire freedom from the typhoid bacillus. On the other hand bacteria, if not removed during the process of filtration, will propagate at an enormous rate in pure water, but fortunately this applies chiefly to harmless kinds.

Water which is at all subject to vegetable growths (generally described as *Algæ*) deteriorates rapidly under storage, particularly if stored in daylight. In underground reservoirs deterioration is less marked. Such vegetable growths are frequently checked by preliminary dosing with copper sulphate in very minute quantities or (as is becoming more popular) with free chlorine.

Unstable nitrogenous organic impurities are converted into harmless nitrates, during filtration in the presence of oxygen, by bacteria known as nitrifying organisms, which are said to act as catalysts, or conveyors of oxygen to transform the organic ammonia first into nitrites and then into nitrates. Pathogenic bacteria, for example the cholera bacillus, are destroyed during filtration by elimination of the organic matter upon which they feed.

Elimination of Germs. Apart from preliminary storage, chlorination, or like means, there may be said to be two distinct methods of eliminating deleterious germs in the process of filtration :

(1) In slow filtration systems by setting up, within the bed, conditions under which organisms are either self-destructive or starved.

(2) In rapid filtration systems by a self-forming film on the surface of the bed (often artificially coagulated and of a more or less gelatinous nature) which is able to sieve out and retain even the most minute organisms.

Artificial Filtrants. There are, in addition, artificially prepared filtrants which operate chemically and bio-chemically. An example is "Polarite," a porous compound of iron, silica, and magnesia, which occludes oxygen in a form apparently more readily active than atmospheric oxygen. "Oxidium," said to be a distinct improvement upon "Polarite," is composed of silicates of lime, alumina and magnesia and iron oxide, and is the active material in the Candy filters described in Chapter V.

Reverting to mineral purifications there has been discovered recently a most interesting process known as the "Permutit" process. The filtrant, described as an artificial zeolite, and prepared by fusing together proportions of silica, alumina, and sodium oxide, is drowned at intervals in a strong solution of common salt. If, then, the salt solution is run off and water, hard due to salts of lime and magnesia in solution, is passed through, the whole of the hardness is removed. Unfortunately for many practical processes, if the hardness be "temporary" free carbonate of soda is left in solution, and this limits the application of the principle to a comparatively few practical duties; but for any process involving the use of soap, laundry work or wool scouring for example, it has proved of great utility. The zeolite loses its softening power after some hours of action, but may be re-vivified indefinitely by periodic drowning in the salt solution.

CHAPTER IV

INDUSTRIAL FILTRATION

It is proposed in this chapter to describe briefly methods and apparatus used in works, having water filtration chiefly in mind, and ignoring for the moment such bacterial and organic impurities as would be considered harmful in the manufacture of foodstuffs, beverages, etc. In other words, the present chapter is concerned only with the removal of visible suspended solids.

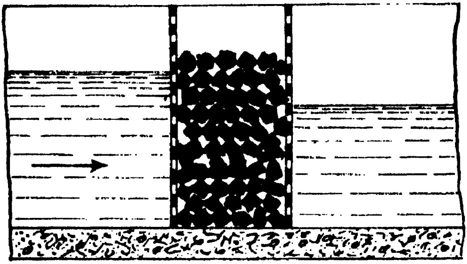

FIG. 5.—ROUGH FILTRATION BY IRREGULAR MATERIAL BETWEEN PERFORATED DIAPHRAGMS.

Sometimes the roughest filtration only is required, obtainable, for example, by the insertion of a grating or screen across the inflow channel. A very common means of rough filtration is to place two vertical metallic screens or perforated diaphragms near together across the channel and to fill in the space between them with coke, cinders, shavings, or any such rough and irregular material as will pack loosely together (Fig. 5).

If the cross sectional area of the channel be not increased—that is to say if the velocity of flow be considerable—this procedure amounts only to rough sieving.

Cloth Filters. Textile fabrics are frequently used and are more or less efficient, dependent upon their nature and the conditions under which they are applied. For example, cotton cloths or cocoa-nut matting may be stretched over timber or metallic frames and mounted across a channel in the manner described in the preceding paragraph. They then operate merely as sieves, the limit of their extractive powers corresponding with the closeness of the weave. Sometimes in rough cloth-filtration of this kind the carrying frames are made to fit into slides in the channels and several spare frames are provided, so that, when one element is clogged, it may easily be lifted out and replaced with a clean spare element (*see* Fig. 6).

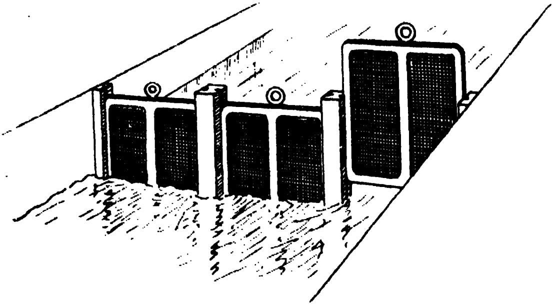

FIG. 6.—CLOTH STRAINERS ON REMOVABLE FRAMES.

A very useful variation of this system of "cloth sieving" is to substitute for flat frames perforated cylinders round which cloth or felt is loosely sewn or tied Such cylinders make joint by their own weight with outlet branches below (Fig. 7), and can quite easily be removed and replaced as they become fouled. They excel the flat frame method in that they permit very large filtering area within a small space and can be made light and handy in relation to their effective area.

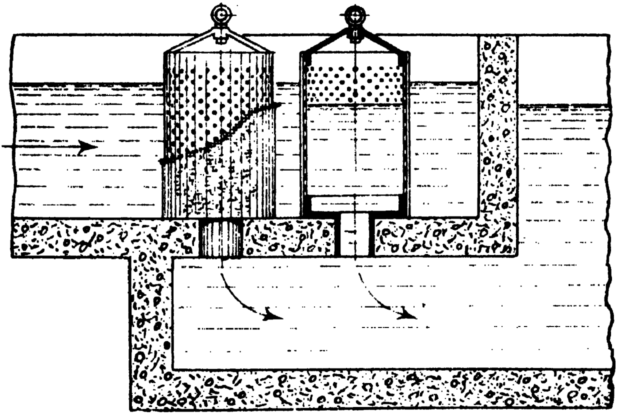

FIG. 7.—PERFORATED CYLINDERS CARRYING FILTER CLOTH OR FELT.

Filter Presses. A well known and useful application of cloth filtration is the filter press, extensively used in chemical and like works and in sewage purification. This apparatus in its

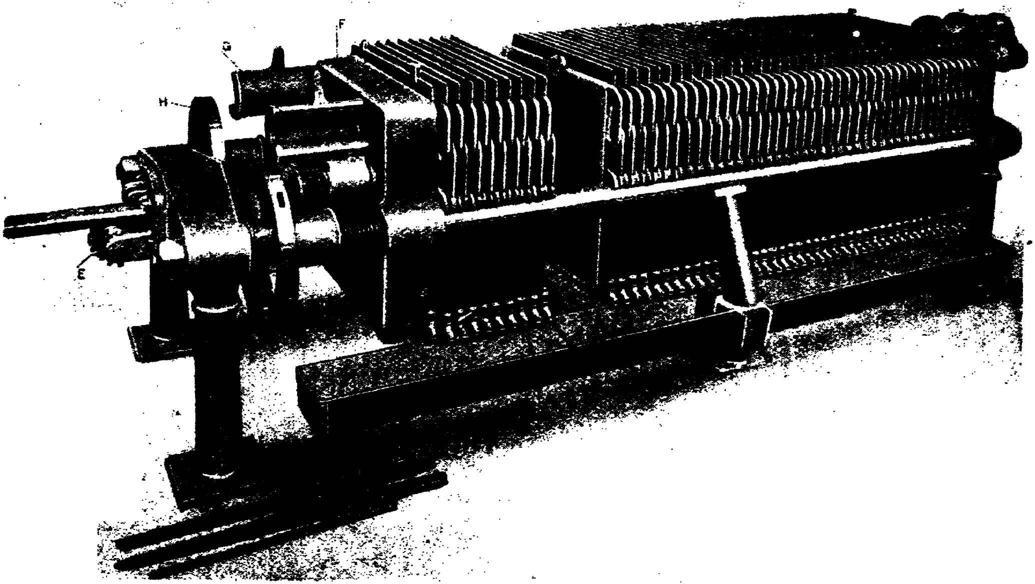

FIG. 8.—HORIZONTAL FILTER PRESS.
(By Manlove, Alliott & Co., Nottingham.)

simplest form comprises a large number of metallic plates specially shaped, serrated, and designed to slide on bars or rails in a strong framework (Fig. 8). Between each pair of plates (Fig. 9) are placed pieces of woven fabric, and the whole battery of plates and cloths is clamped tightly together by a powerful screw or by hydraulic ram

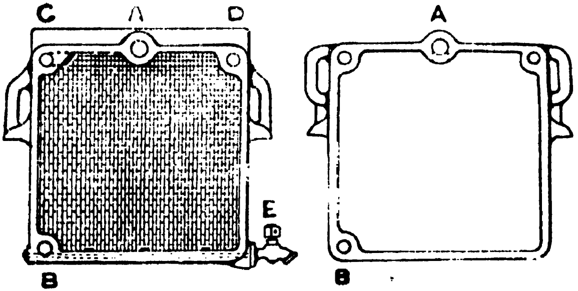

FIG. 9. PLATE AND FRAME FOR FILTER PRESS SHOWN IN FIG. 8.

A—Feed inlet.
C—Air Outlet.
B—Wash water inlet.
D—Wash water outlet.
E—Outlet for filtrate.

so that the cloths make tight joints at their edges but present clear space within the frames.

The liquid or sludge to be treated is pumped through orifices provided in the frames, often under considerable pressure. The solid matter is retained by the sieve action of the closely woven cloths, while the liquor escapes and drains away. When the full capacity has been dealt with, the pressure on the plates is released. The plates may then be separated and the cakes of sludge may be removed from the cloths and conveniently handled.

Frequently the function of the filter press is the converse of that of the normal filter, that is to say to obtain in convenient form valuable suspended matter, the liquor expressed being useless and run to waste. Filter presses and apparatus of analogous nature are also used largely in expressing beer from yeast and oils from seeds or animal fats, in which case both the cake and the effluent are valuable products. Fig. 10 shows a cage-type filter press, with rolls and heating kettle alongside, for dealing with oil-bearing seeds or nuts.

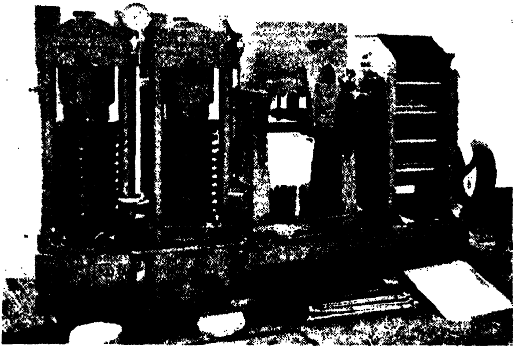

FIG. 10.—VERTICAL FILTER PRESS FOR SEED OIL EXPRESSION.
(By Manlove, Alliott & Co., Ltd., Nottingham.)

There are many modifications in the details of filter presses, chiefly concerning the design of plates and arrangement of cloths. Frequently, in chemical industry, timber plates are substituted for metal to withstand acid and alkaline action, teak or pitch-pine being generally employed. In such processes, particularly when the sludge cake is a valuable product, serrated plates and open frames alternate, with cloths between each plate and frame, so that the cake is obtained of convenient form and thickness. Again, by forming suitable ports and openings in the plates and frames, arrangements can be made whereby, after formation of the cake but before its release, wash water or other solvent liquor may be forced through with the objects of cleansing the cake or dissolving out entrained matter. Full details of these many ingenious devices cannot be given in this book but they are generally well described in makers' catalogues.

Feed-Water Filters. Still another application of the filter cloth is common in apparatus used largely on steamships, for the partial elimination of oil from boiler feed-water. This is again the application of the perforated cloth-surrounded metallic cylinder but, as the operation is performed under high pressure between the feed pumps and boilers, it is essential that the filter chamber shall be of small dimensions to avoid danger of bursting. Therefore it is imperative for efficiency that the maximum possible cloth area shall be presented within the minimum possible space. Fig. 11 illustrates in section one of these filters, with serrated cylinder grids, but this is only one of the many forms which have been patented, the objects being to obtain the maximum area and to facilitate renewal of the cloths.

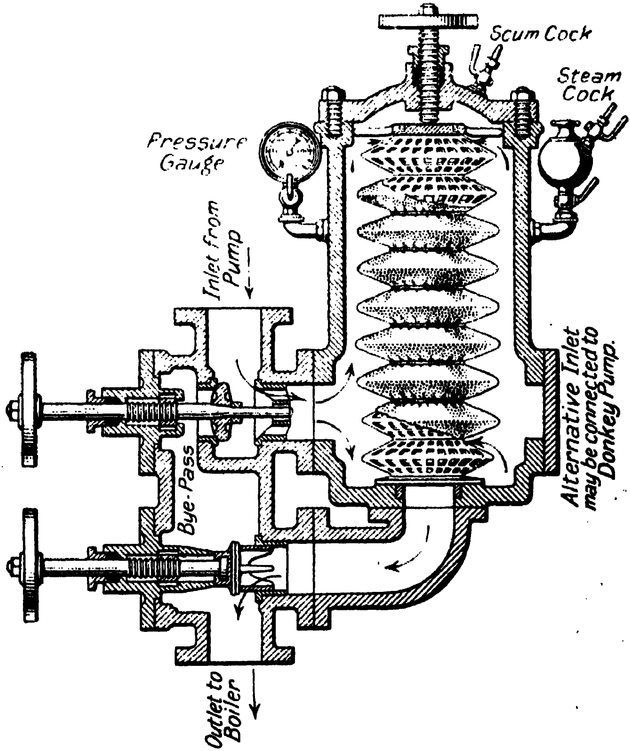

FIG. 11.—HIGH-PRESSURE FEED-WATER FILTER.
(By Glasgow Patents Co., Ltd., Glasgow.)

Generally, cloths stretched tightly over grids can only be regarded as strainers for suspended solids. In these feed-filters we have not to deal with solids but with a foreign and non-soluble liquid (oil) in suspension or emulsion. As a rule flannel or Turkish towelling is used as filtering medium and, while it cannot be relied upon to remove all traces of oil (which would only be possible following chemical coagulation) there is no doubt that the rough fibrous surface of such media does exercise a peculiar attractive preference for oily matter, and that filters of this type are of considerable value in long voyages. They can be partially cleaned without opening by isolating with the valves shown, injecting soda, and steam, and blowing off the sludge.

Upward Filtration. When the efficiency of a filter must depend largely upon the "internal subsidence" principle (p. 11), that is to say when the medium of which the filter bed is composed is so coarse in relation to the suspended matter to be filtered that but little sieving action is to be expected, there is little doubt that the best results are obtained when allowing the water or other liquid to rise slowly through the bed from below. Thus for many classes of suspended impurity, for rough industrial work, and particularly following water softening, the simple coke or clinker filter shown diagrammatically in Fig. 4 is excellent. Deposition of the light suspended matter takes place in the numerous pockets and interstices formed between the lumps of coke, and we have the Wanklyn subsidence theory exemplified very perfectly. The condition essential for satisfactory work is that the speed of flow shall be reasonably slow. With the fine chalk suspensions in newly-softened cold water rates of rise of from 30 ins. to 120 ins. per hour (calculated upon the gross area of the filter chamber) give good results. This is about equal to from 15 gallons to 60 gallons per sq. ft. of filter chamber area per hour.

A filter of this class will intercept and hold a large amount of suspended matter before requiring cleaning, and, up to a certain point, often improves in efficiency as it becomes fouled, due to the attraction which old precipitate exercises upon new suspended matter. When cleansing becomes necessary, that is to say when the interstices are so choked with sediment that the velocity through the restricted passages tends to disturb the earlier accumulations, such a filter may be cleansed effectively by lowering the water level below its base and turning a hose-pipe upon it from above with considerable force. It will readily be understood that a filter of this upward-flow class using a medium of finer nature, sand for example, is hardly practicable unless one is prepared to renew the bed every time it is fouled, as such finer material cannot be washed out from above in the manner described.

A medium commonly used in industrial filters of the upward flow type is *wood wool* (fine timber shavings). Its one and only claim is initial cheapness. The shavings are difficult to pack symmetrically, and are apt to become pulpy and to settle down in dense masses locally, with thoroughfares of excessive size elsewhere through which the liquid short-circuits rapidly without deposition. The shavings cannot be washed down with the same efficiency as coke by means of a hose-pipe, and their removal, if the sediment be of at all an offensive nature, is an operation of the filthiest description.

On the other hand, *cloth filters* may be used with great advantage and efficiency in upward filtration, and, if their operation were better understood, there is no doubt that their employment would be widely extended. When mounted vertically on gratings, cloth filters can only be regarded as strainers, but when mounted horizontally across the course of a slow vertical current, their behaviour is quite different. In the first place they will of course directly intercept matter larger than their pores but, with many classes of suspended matter, a further phenomenon ensues. Smaller and lighter particles actually get through the pores but settle down and build up upon the upper surface like snow on the ground. After a few hours' operation this settled matter becomes itself the true filtrant for finer sediment, and, always assuming that the rate of flow is not excessive and that the suspended matter is of suitable class, the degree of efficiency obtainable is remarkable.

Such filters are advantageously arranged as shown in Fig. 12. Metallic frames, lightly designed, have the filter cloths roughly sewn over them and are placed over openings in a timber frame mounted within the filter chamber, making joint by their own weight. The liquid rises through the cloths at low speed (say, from 30 ins. to 60 ins. per hour).

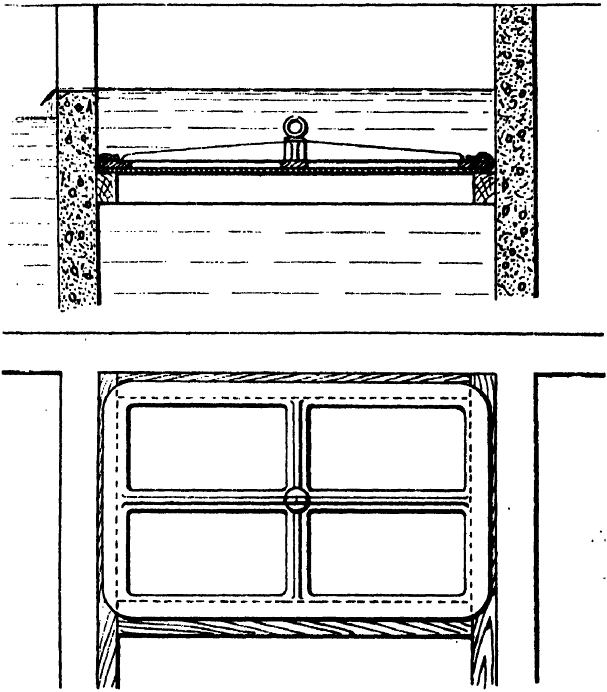

Fig. 12.—Upward-flow Cloth Filters.

After the filter has been in use for an hour or two (depending, of course, upon the amount and nature of the suspended matter) it will be found that a film of gradually increasing thickness forms upon the upper surface and becomes itself a most effective filtering medium. In course of time, the cloths become so clogged with deposit that they tend to bulge upwards. Then the frames are removed one by one, at intervals in the order appearing necessary, and spare cloth-frames are dropped into their places. It is not usually necessary to renew the actual cloths for long intervals as, by drying and beating them, all the solids are shaken off and they are ready to be used again.

Downward Filtration. *Open Filter Beds.* For industrial service, which we may for convenience regard as the removal of visible suspended matter from water or other liquids, without regard to any chemical or adsorptive change of condition, the open sand filter is largely used. In this sphere of utility it is to be regarded only as a sieve or strainer, for, if matter in suspension is not retained on the surface, it is hardly likely to be intercepted at a lower level.

Open sand filter beds are frequently constructed of very large area for removing fine suspended matter from incoming water and also in connection with the removal of deleterious solid and colouring matters in trade effluents but, in the latter duty, some chemical treatment must precede filtration, to throw dissolved impurities into suspension and filterable condition.

The general type of all such filter beds is indicated diagrammatically by Fig. 13. A shallow tank with concrete or cement bottom, often channelled to ensure getting the clear effluent away, has laid down thereon means of collection over the whole area, for example earthenware pipes with open joints, bricks or tiles laid close together but uncemented, or perforated pipes. These are covered with a bed of coarse material, for example coke, gravel, stone chippings, saggars or the like, graded to pass a comparatively large mesh. Above this is a level bed of fine sharp sand or crushed quartz. In industrial work it may be said that the thicknesses of these zones of material have little or no effect upon the filtration. It is the fine material at the surface which provides the extractive action, the coarser material below merely acting as a support or carrier for it. The depths of the filtering, carrying, and draining zones therefore are determined chiefly on maintenance considerations, that is to say to prevent the fine

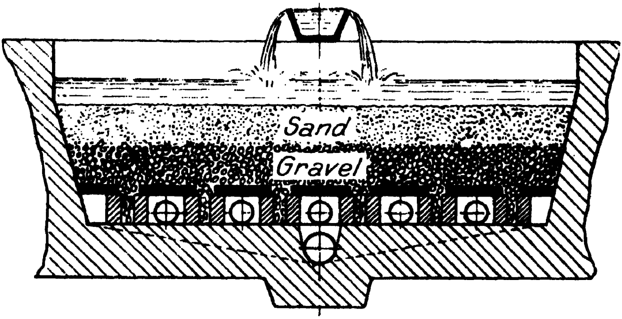

FIG. 13. OPEN SAND-FILTER.

sand or quartz from finding its way in undue quantities into the interstices of the coarser zones below.

A most important point in working filters of this class is that there shall always be a considerable depth of water above the bed. This is primarily necessary as a means of forcing the water through, but there is a second and very important reason, namely, that working with thin beds the cascade of incoming water must have no effect in disturbing the sand surface. It is even advisable, if practicable, to fill up the filter in the first instance through the outlet orifice, and it is good practice, if convenient and not too costly, to arrange that clean water may be pumped the reverse way through the bed for cleaning, as will be explained hereafter in connection with rapid filters. Filters of this class are efficient for extracting all but the finest mineral and vegetable matter suspended in river, stream, and surface supplies, the deposit being retained generally upon the surface of the sand. As it forms a film on the surface the efficiency increases, but conversely the flow decreases. Sometimes, however, suspended matter is so finely divided, so nearly approaching the colloidal state, that it will find its way through the finest sand or crushed quartz. Then one must resort to preliminary dosing by some coagulant, as described in Chapter I, to put it into filterable condition.

The output capacity of filters of this class will naturally vary with the head of water and the degree of clarification desired. Suitable heads range between 1 ft. and 3 ft. measured from the water level in the bed to the level in the clarified water tank, and the latter level should always be above the level of the sand, or otherwise the latter might be left bare.

For fine filtration, speeds through the bed are kept as low as 6 ins. per hour (equal to $3\frac{1}{8}$ gallons per sq. ft. per hour) but, on the other hand, speeds of 20 ins. or even 30 ins. per hour are frequently employed for, as a rule, ground space is valuable in the neighbourhood of factories.

When so fouled that they will not pass their quantum of water, these filter-beds are cleaned by raking off the top surface and re-levelling, as required, with clean sand. Filter beds of this class are, as a rule, designed of large superficial area. It has been stated that almost all the suspended matter which need be extracted is intercepted at the surface and that the depth of sand, gravel, and the like generally provided, often 3 or 4 ft., is necessary only because of the practical difficulty of maintaining evenness of distribution over a large area. This point was brought home forcibly to the author some years ago and led him to design and patent a sectional form of open filter. This form has been applied to many water softening plants with conspicuous success and would probably prove superior to the large-area bed for general open applications. A short description therefore is given.

Sectional Open Filter. **The total filtering area**

is divided into long channels, usually 2 ft. wide, 3 ft. deep (rectangular), and 4 ft. deep to extreme bottom of prismatic section (*see* Fig. 14, which represents in perspective the top of a water-softening plant, with three such filter channels). Near to the bottom are mounted collecting pipes *a*, perforated on the under side, which pass out and discharge filtered water through the valves, b_1,b_2,b_3. At short intervals at the 3 ft. depth, stretcher bars *c* are mounted which support metallic plates perforated with fairly large holes, and which act as the carrier for cocoa-nut matting, *d*. This matting acts in turn as the support for the filter bed proper, *e*, which may be of fine sharp sand, crushed quartz, or any material selected as suitable for the particular suspended matter. Penstocks, f_1,f_2,f_3, are mounted at the far end, slightly above the normal working water level; g_1,g_2,g_3 are the entrance sills.

The turbid water rises through preliminary mat roughing-filters such as are described in Fig. 12, which rest upon the timber framework *l*. This rough-filtered water flows over the sills, g_1,g_2,g_3, which are about 12 ins. higher than the sand surface. Practically all matter in suspension is retained upon the surface of the sand, and the clarified water percolates through the bed, finds exit through the collecting pipes, *a*, and is discharged through the boxes, h_2,h_3. These boxes constitute a device whereby, by setting the pipes, *m*, at a correct height, a predetermined minimum head of water over the sand may be ensured: that is

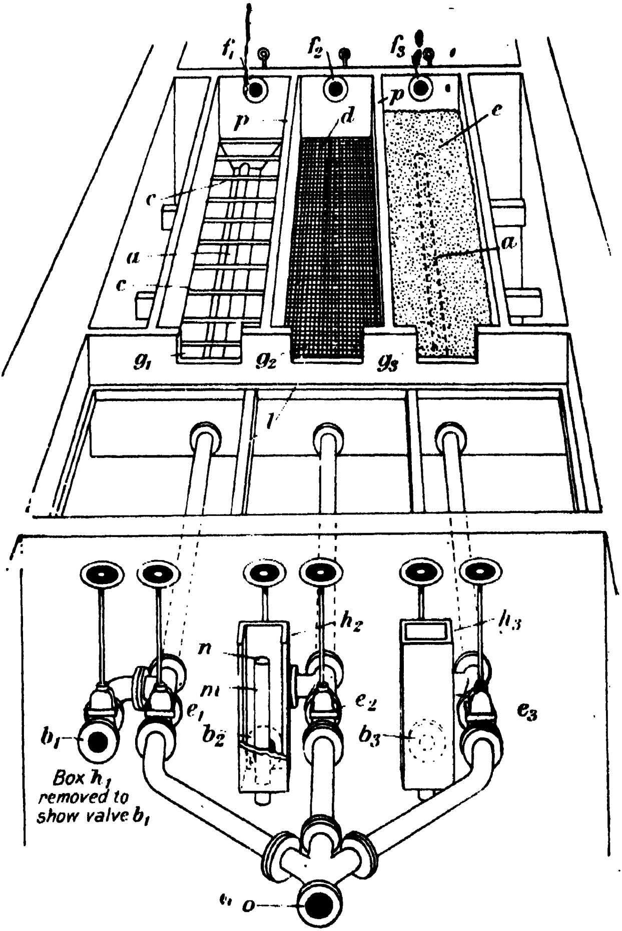

FIG. 14.—SECTIONAL-TYPE OPEN SAND-FILTER.

This type of filter can be cleansed quickly without interrupting operation and may therefore be of much smaller area than ordinary open filter beds.

to say the level n, is usually 9 ins. to 12 ins. above that of the sand, so that the latter can never be uncovered.

When so much deposit has accumulated as to reduce unduly the rate of flow (say in the centre channel) the valve b_2 is closed, the valve e_2 is opened and also the penstock f_2, while a specially designed diaphragm is hung temporarily over the sill g_2. A large volume of previously filtered water is then sent the reverse way through the pipe o (generally by a steam operated bilge-ejector but sometimes by a centrifugal pump) for about two minutes. The reverse current has the effect of lifting the sediment from the surface of the sand and to the level of the penstock f_2. A special trimmer rake (Fig. 15), is now run along the edges p, of the channels from the sill-end to the penstock-end. This just trims without seriously disturbing the sand surface and at the same time swills the scum away through the penstock. Properly conducted, the whole cleansing process occupies about 10 minutes and requires about $1\frac{1}{2}\%$ of the total

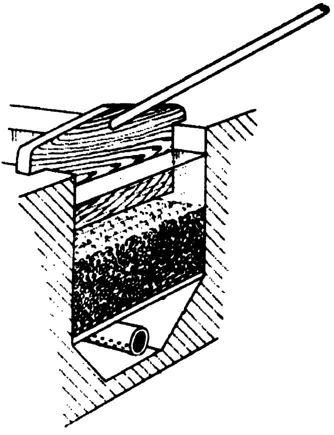
FIG. 15. TRIMMER RAKE FOR SURFACING SAND AND REMOVING SCUM.

water filtered (which, in the case of water softening, is not wasted, but comes back for re-filtration).

It is obvious that any one of the three sections can be thus cleansed while the others remain operative.

Rapid-Type Open Filters. There is still another type of open filter, generally known as the "Rapid-Type," which, with many variations of detail, is being made by as many firms in this country and America. Rapid pressure filters of the enclosed type are described later (pp. 47 *et seq.*). The word "pressure" is, of course, relative and may refer to a few feet head or to a pressure of many pounds per square inch. Obviously, the greater the head or pressure available, the more rapidly water may be forced through the bed. Also when the bed is clean it will, under given head and if not automatically controlled, pass more water than when fouled, and the rate of flow will decrease as fouling increases.

In the large open beds described above, the cleaning process is an undertaking of no inconsiderable magnitude and involves a large amount of time. The large area, therefore, is provided chiefly with a view to running over long periods.

The pressure filters described in the next section are equipped with mechanical, hydraulic, or pneumatic devices, to render the cleaning operation very simple and rapid, and the *rapid open filters* represent the application of the same principle to open tanks. In other words they are *low* pressure filters, the pressure being the head in the open tanks over the sand. Fig. 16 is typical of this class of filter. During the filtering process, a head of perhaps 1 ft. to 3 ft. is maintained above the quartz bed, and the filtered water finds egress through the special nozzles shown embedded in concrete at the bottom. At cleaning periods the inlet valve is closed, filtered water is returned through the collecting nozzles with sufficient force to put the quartz more or less into suspension and the radial rakes are rotated, whereby the particles of quartz are thoroughly scoured by friction, and the released mud is discharged to the drains.

In some designs the filter bed is not agitated mechanically during cleansing but, instead, steam or compressed air is injected from below. This method is simpler and less costly but it is also less drastic ; for many services, however, it appears to be quite efficient.

Among the rapid filters of this class are the American "Jewell" type. A filter of this type, 17 ft. in diameter, is illustrated in Fig. 17. The method of operation is essentially the same as that of the Bell type.

Bell, Jewell, and like open rapid filters are rated to pass about 100 gallons per sq. ft. per hour which is equal to a flow-rate of about 190 ins. per hour through the bed.

Pressure Filters. There is really no fundamental difference in principle between the downward flow open filter described in the last section and the

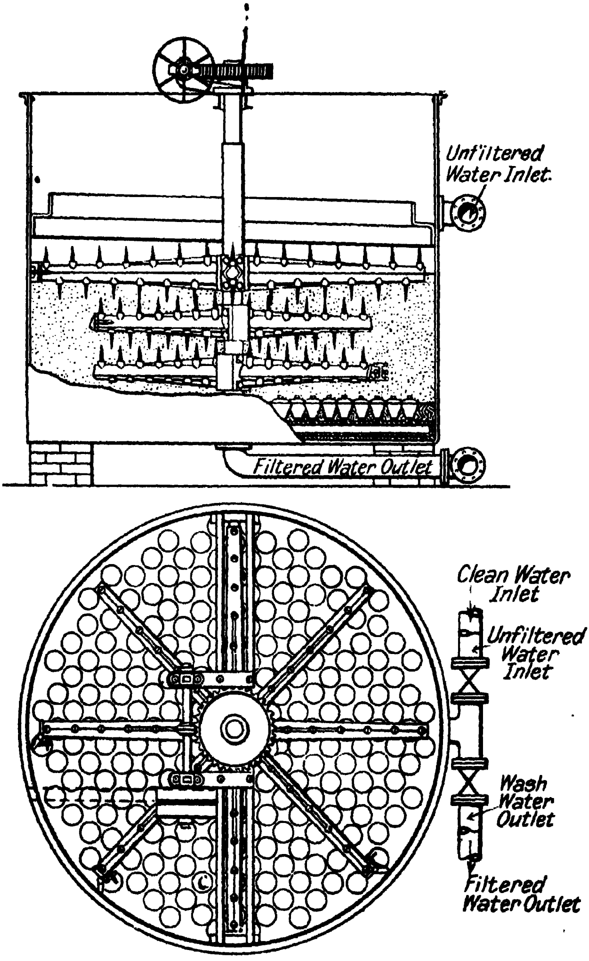

FIG. 16.—RAPID-TYPE OPEN FILTER.
(By Bell Bros., Ravensthorpe.)

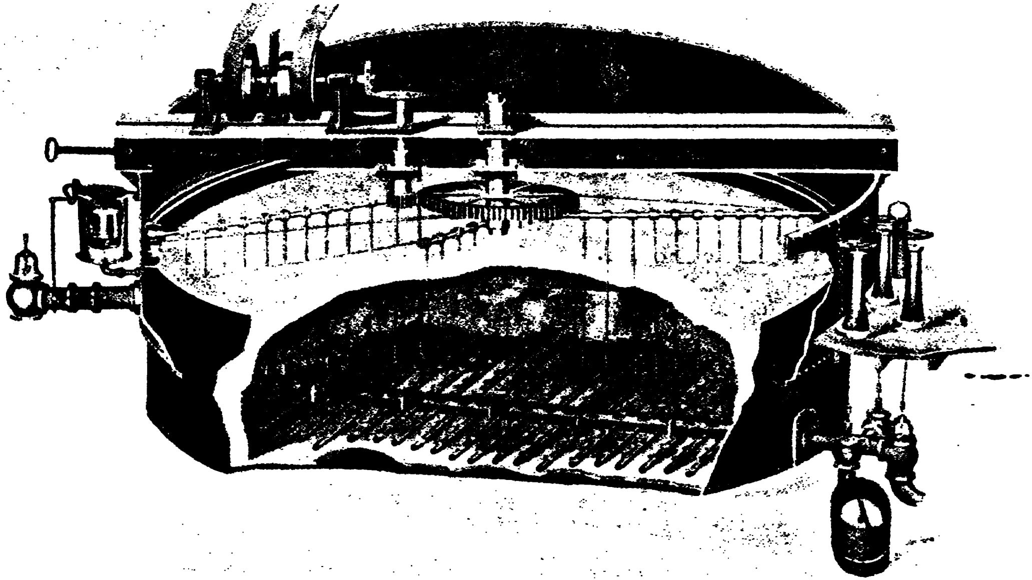

FIG. 17.—JEWELL RAPID-TYPE OPEN FILTER.
(By Jewell Filter Co. Inc. York.)

pressure filter but—whereas the former work only under the head of a few inches or feet of liquid over the filter bed and are capable of passing only a limited amount of water or other liquid—the latter are totally enclosed and may have large differences* of head or pressure between their inlet and outlet branches. Consequently, very large volumes *may* be forced through beds of small area, and, if sieve action only be considered, the degree of purification will be substantially as good at high velocity as at low velocity. Accumulation of silt and mud on the surface will, however, be correspondingly rapid, so that thorough cleansing is required at more frequent intervals, and devices for cleaning the filtering material constitute the chief and most interesting features of the many designs of pressure filter.

The chief reason for the great and growing popularity of pressure filters is that, in relation to output, they occupy very little space; this, in busy manufacturing districts, and abroad where transport is costly, is synonymous with low capital outlay. Also, as regards supervision and attention in large installations, it is obvious that concentration of plant within small space offers economic advantages. Pressure filters are installed for pressures up to or exceeding 200 lbs. per sq. in. for boiler feeding and like purposes, and, *en batterie*, for purifying water from high level reservoirs at heads of 500 ft. or more.

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* The possible rate of filtration does not depend upon absolute pressure in the filter, but upon the *difference* between the inlet and outlet pressures. It is not usual in high pressure installations to work at excessive rates.

It may be repeated however that, at these high pressures, they must be regarded only as strainers; if they are to be applied to effect organic and bacterial purification, they must be operated at very moderate speeds. (*See also* p. 57.)

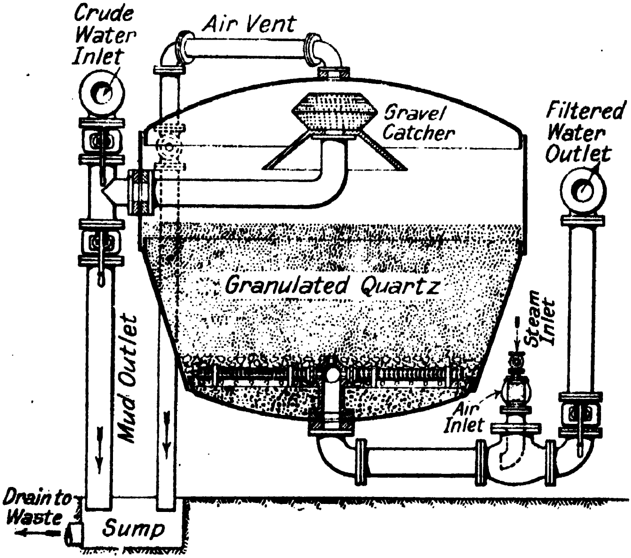

FIG. 18.—ROYLE PRESSURE FILTER.
(By Royles, Ltd., Manchester.)

Royle Pressure Filter. Fig. 18 shows in section the Royle pressure filter which is, in all its main features, similar to some dozen or more designs by various British firms. It may be regarded as an enlarged chamber in the water main and the loss in pressure between the crude water inlet and the filtered water outlet branches is a measure of the pressure required to force the water through the comparatively thick bed of quartz. The inlet and outlet pressures are generally indicated by Bourdon gauges fixed at the respective branches, and the readings of these gauges give a clear indication when the bed is so fouled as to require cleansing. The filter chamber is made of strong riveted steel plates and is generally tested by hydraulic pressure to at least 50% in excess of its working pressure, just as a boiler would be.

The conical form of the lower portion of the Royle filter is preferred by some makers as, the straining function taking place at the surface, the output is not thereby reduced, while it is believed that the quartz settles down more symmetrically in the cone. Many makers, however, consider this to be a refinement unnecessarily expensive, showing inappreciable improvement in effect. At the base, internally, are mounted a series of radial copper pipes, finely perforated, and embedded in cement. Upon this bed rests sharp sand or finely crushed quartz to a depth of 3 ft. or 4 ft. In working, crude water is introduced near the top where a sieve is fitted, for the interception of any very coarse impurities, and also a distributing cone. An air vent-pipe and cock are also provided at the top, so that there may be no "air lock" and the chamber may be absolutely full of water.

The applied pressure forces the water down through the quartz, suspended matter being strained out, and the filtrate finds exit through the perforated pipes at the bottom leading to the outlet branches. When it is found that the bed is fouled, the difference in pressure indicated by the inlet and outlet gauges having risen from, say, 2 lb. to 10 lb. per sq. in., cleaning becomes necessary. To effect this, the water inlet valve is closed and the valve to the sump is opened. Pre-filtered water is forced the reverse way through the bed, together with air, induced by the steam injector. By these means the mud and scum are floated up from the surface, the particles of quartz are put more or less into suspension, so as to exercise a scouring action upon one another, and the dirt escapes through the mud-discharge pipe to the sump and drain. When the water runs clear from the mud-discharge pipe it is assumed that the filter is again clean, and the original cycle is resumed.

The Bell Pressure Filter. Fig. 19 illustrates in part section the Bell patent pressure filter which is fundamentally similar to the Royle type described above but embodies a quartz-scouring device of much more drastic nature. It will be observed that there is a central shaft passing vertically upwards through the bed and through a stuffing box in the cover. This shaft is rotated mechanically during the cleaning periods. It carries, internally, radial pipe arms which are perforated and in communication with a source of pre-filtered water under pressure. These arms also carry vertical pins which serve as rakes.

When the bed, as shown by pressure gauges, is

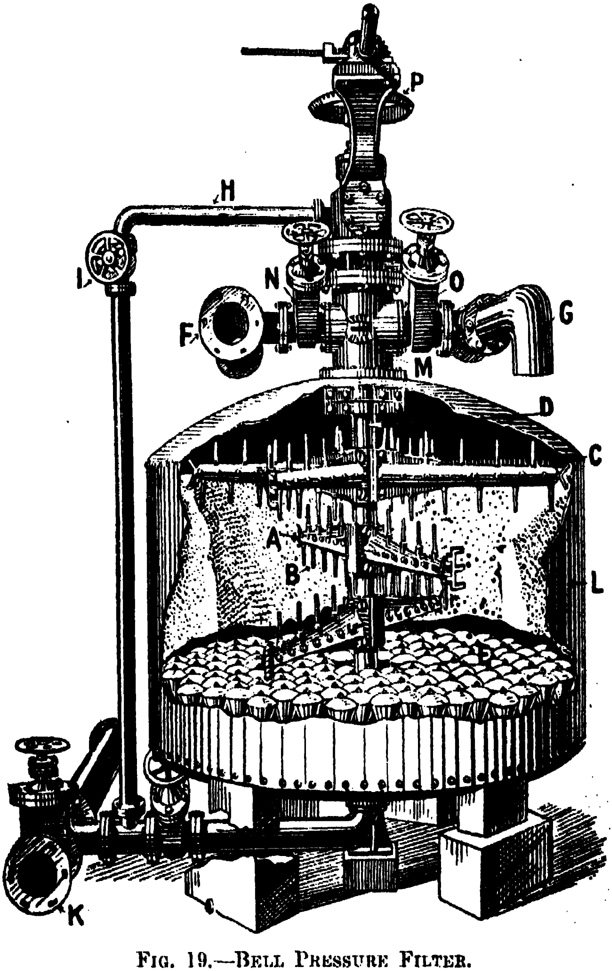

FIG. 19.—BELL PRESSURE FILTER.
(By Bell Bros., Ravensthorpe.)

so fouled as to set up excessive resistance, a mud-discharge valve is opened, the inlet valve is closed, and a current of filtered water is induced the reverse way to the normal current just as in the Royle filter, which loosens the quartz or sand and puts it more or less into a condition of suspension. Then for a few minutes the central shaft is rotated, filtered water entering forcibly through the perforated arms, and the rakes thoroughly disturbing and agitating the bed material so that each particle is thoroughly scoured. It is claimed, and from our many observations we think justly, that by means of these operations the filtrant is maintained in practically perfect condition ; perhaps not indefinitely, for this violent scouring action must in time rob the medium of some of its sharpness, bringing it from the condition of the coke in Fig. 4 to that of the billiard balls in Fig. 3, but renewal of the filtrant at intervals of two or three years is not a very serious consideration.

Before leaving the Bell filter, attention may be drawn to the efficient type of collecting device employed. There are screwed into the discharge chamber a large number of conical boxes, each fitted with a lid having rather large perforations, and each filled with fine shingle. These boxes are clearly visible in Fig. 19, and it is claimed that they are less liable than perforated collecting pipes to be choked by leakage inwards of fine sand or the like.

Mather and Platt Pressure Filter. Fig. 20 represents in sectional elevation a type of pressure filter patented by Messrs. Mather and Platt, Ltd. (Manchester), but now also the property of Messrs. Bell Bros. The author has had more personal experience with this than with any other type

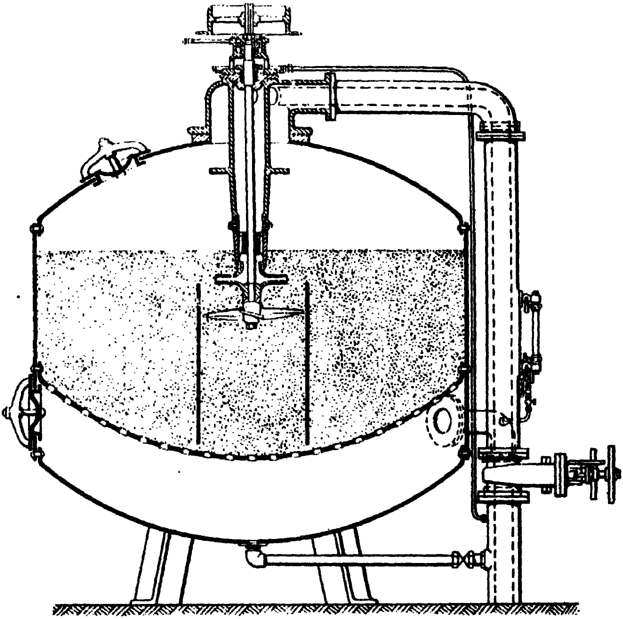

FIG. 20.—MATHER AND PLATT PRESSURE FILTER.

of pressure filter and, without intention of making invidious comparisons, regards it as a close approximation to perfection for most industrial duties. It is in broad principle, during the filtration process, exactly like the Royle and Bell filters. Instead, however, of the Royle radial collecting pipes and the Bell collecting nozzles, this filter casing is formed with a roomy internal double bottom into which finely perforated ferrules are screwed *from the underside*, and are thus accessible for examination and replacement without disturbing the filter bed. This, in itself, is a considerable advantage, but the distinguishing feature of this filter is the method of cleansing the bed when fouled. It will be seen that there is an internal tube mounted centrally and extending from within a few inches of the top of the bed nearly down to the false bottom. Within this is carried, upon a vertical spindle, a small helical impeller similar to the screw propeller of a small launch. This can be rotated at high speed either by belt (as shown) or by a directly-coupled electric motor.

At cleaning periods, the sand or quartz is put into partial suspension by opening the mud valve and sending a forceful current the reverse way through the perforated ferrules. The impeller is then rotated, with the result that the quartz particles are induced in a violent stream up the central tube, returning to the bottom outside the tube, and so, with the expenditure of very little power, every particle is thoroughly scoured from coatings of mud, grease, or the like which may have adhered to it. At the same time, a current of water is also forced down the upper sleeve and, through jets, radially outwards at the surface of the bed; this assists in directing the circulation and in completing the scouring process.

CHAPTER V

FILTRATION OF PUBLIC SUPPLY WATER

THE more one studies available literature the more is brought home the difficulty of writing concisely and directly upon the filtration of potable water. The author has not been personally responsible for the design or maintenance of such filtration plants and the subject cannot be regarded as coming wholly within the capacity of the engineer; the chemist and biologist are at least equally important contributors towards success. Again, the conditions for no two districts are alike, either as regards quality of supply or nature of demand.

In the space here available it is only possible to indicate superficially the nature of the various types of plant recently installed, the class of work which they accomplish, and their respective merits and limitations, and to direct those who need more complete information to the best and most recent literature on the subject and to the opinions of specialists.

Slow Filters. The most commonly used type of waterworks filtering plant comprises two or more open sand filters of large area similar to Fig. 13 in general section, the whole bed being from 3 ft. to 4 ft. deep. The working head of water over the sand should never exceed the depth of the bed, and usually averages considerably less.

It is common and good practice to provide large open reservoirs for prolonged storage and sedimentation of the raw water prior to filtration, and sometimes also for chemical treatment. For example, sulphate of alumina or lime water is employed during this period of impounding to hasten and improve sedimentation, or to harden or neutralize waters exercising solvent action upon lead. Sulphate of copper (say 1 part per 10,000,000) is often added to check vegetable growths. Storage after filtration and prior to distribution to the mains is advantageous in underground reservoirs.

Open filters of this type are frequently of very large superficial area; for example half an acre is quite common, and average rates of filtration are from 1,000,000 to 4,000,000 gallons per acre per day. A speed of 4½ in. per hour fall through the bed is considered a good normal average.

As regards organic and bacterial efficiency filters of this class, newly prepared or immediately after cleaning, may be regarded as wholly inefficient. As has been stated previously clean sand has substantially no effect in removing, by straining or adsorption, the minute organisms which are the chief source of contamination. The filter must be *ripened*, that is to say, raw water must be passed, in quantity depending upon its nature, temperature, and other considerations, for a period averaging 48 hours, during which time the filtrate is run to waste. "Ripening" is a convenient general term to describe roughly several effects which are admittedly only slightly understood. During the cleaning process the bed becomes aerated. As water is run through, the particles of sand in the upper layers acquire a slimy coating, and a thin film of mud containing mineral, vegetable and animal matter of the most finely divided nature develops upon the surface. It is to these phenomena that the true cause of efficiency may be traced.

Carefully prepared and operated, such filters are known to reduce the bacterial contents of water by 95% to 98%, with entire elimination of pathogenic germs, and to bring organic impurities, appearing as free and albumenoid ammonia, well within the recognized limits of safety. The time of running between cleaning periods varies greatly, dependent upon the nature of the raw water and atmospheric conditions. While 20 days continuous work is a fair average, such filters have been known to work efficiently as long as 180 days.

Periods when cleaning is necessary are determined mainly by two considerations—

(1) Resistance to flow as the bed becomes fouled ;

(2) Tests, chemical and bacteriological, upon the effluent.

Puech-Chabal System of Slow Filtration. This system of filtration of public supply water is of French origin and is reported to show remarkably good and consistent results at Paris and in other continental installations. A portion of the London supply is purified by Puech-Chabal filters and the results are stated to be consistent and excellent.

The system may be described as an inversion of the ordinary slow filter as illustrated in Fig. 13, that is to say the coarse material, which forms the base of the normal slow filter, comes first in the Puech-Chabal. Instead however of being superimposed in one bed the material is graded in several successive beds as shown diagrammatically in Fig. 21. It will be noted in this sketch there are really five filters in series. Those numbered 1, 2, and 3, are called *degrossisseurs* and are of comparatively small but increasing area, charged with coarse gravel, also graded. For example in No. 1 the pieces average walnut size, in No. 2, bean size, and in No. 3, pea size. The pre-filter is like an ordinary open filter having its top layer formed of coarse sand, and the finishing filter is substantially a repetition of this, but of five or six times the superficial area, and with a top layer of very fine sharp sand.

As the raw water passes successively through the units of this system, the coarse material in the early units becomes coated with slime, which is found to develop conditions for purification, physical and biological, comparable with those found at the surface and in the upper zones of a "ripened" bed of normal design. Thus the roughing elements, which can be readily isolated and cleaned, perform a very large portion of the important duty, and when the water reaches the pre-filter and finishing filter for final clarification

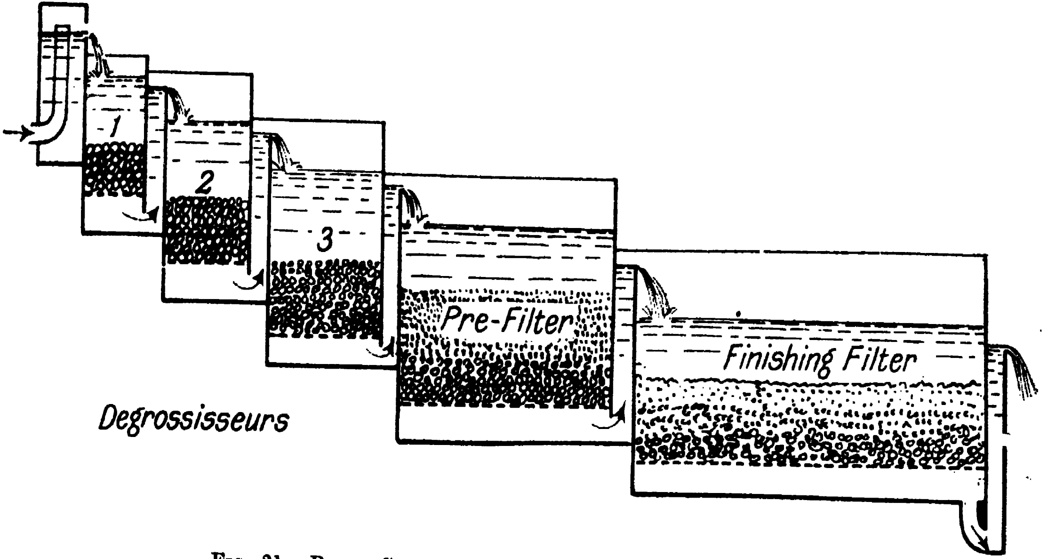

FIG. 21.—PUECH-CHABAL FILTRATION SYSTEM (DIAGRAMMATIC).

it carries so little suspended and organic matter that the beds are largely protected from surface growths and accumulations, and will work efficiently over very long periods. A full and lucid description of the design and operation of the Puech-Chabal system will be found in a paper read by Mr. Walter Clemence.*

Rapid Filtration of Public Supply Water. The trend of recent events seems to be in the direction of gradual supersession of slow filters by those of the rapid or mechanical type. The former have the strong and influential support of many leading scientific and practical experts, but the latter have been wonderfully developed during the last ten or fifteen years, and will probably survive, if only by reason of their lower installation and upkeep costs. It has been proved repeatedly that modern rapid filters give results which meet all the requirements of biological and medical authorities and, what is even more important, they meet these requirements consistently. Slow filters, by reason of their magnitude and consequent difficulties of supervision, may be delivering a perfectly satisfactory effluent at one time and, an hour later, be discharging a very bad one. The only real check upon them is by constant testing. Rapid filters on the other hand, having once shown themselves capable of attaining the desired degree of purification, may be expected only to fall away from this following gross carelessness. They are usually concentrated within a small area and, being well housed, they are less subject to climatic influences; any incidental cause of inefficiency should be apparent at once.

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* *Proc. Inst. Mech. Eng.*, May, 1916.

We have already described several designs of rapid filters, both open and closed (pressure) types, in Chapter IV; *see* Figs. 16 and 20. All these are employed for the purification of public supply water, substantially without modification so far as their internal details are concerned. The volume of water with which they are required to deal in this service is generally so large that a number of filters must be used simultaneously. Fig. 22 is from a photograph of the filter house at Shrewsbury in which is a battery of twelve Bell pressure filters capable of passing 2,400,000 gallons per day. It is typical of many such plants.

Rapid filter installations of the open type, working under 2 ft. or 3 ft. head or even less, generally comprise units averaging 17 ft. diameter. Probably the American Jewell Co. have fitted more of this type than any other firm and they have built units up to 22 ft. diameter. Pressure or enclosed filters do not as a rule exceed 8 ft. diameter, chiefly because, under high internal pressure, large diameter involves heavy plates and costly workmanship.

Use of Coagulants. Though the units for potable water supply are substantially like those used for rougher industrial work the conditions under which they are operated differ considerably.

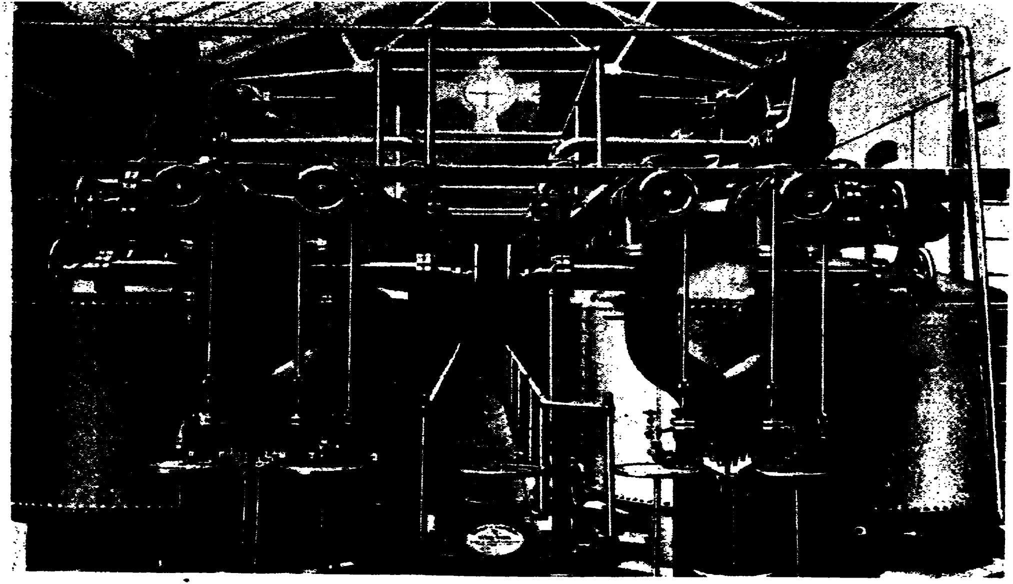

FIG. 22.—BATTERY OF RAPID-TYPE PRESSURE FILTERS FOR POTABLE WATER SUPPLY

We have shown previously that clean sand or quartz is alone inefficient in eliminating germ and organic contamination, but we have also explained briefly the principle of coagulation. In slow filtration the use of artificial coagulants is comparatively rare. In rapid filtration it is vital and essential. On its way to the filter the water receives small measured doses of sulphate of alumina. If the water be acid or very soft it must also be dosed with lime water. In the foreground, Fig. 22, may be seen the small pumps which systematically supply these reagents to the incoming water during its progress through the supply pipes. The effect of this treatment is to produce in suspension gelatinous matter, aluminium hydrate, which forms a film on the surface of the bed impervious to almost every form of deleterious matter. Until this film has formed—say, during ten minutes or quarter of an hour following starting a filter after cleaning—the filtrate should be discarded to the drains.

Having in view the importance of maintaining this film intact, water works' filters of the enclosed type are rarely worked at head differences exceeding 10 ft. and, in both open and pressure installations, the greatest care is taken to avoid sudden variations in the rate of flow and all other possible causes of injury to the film, when once it has formed.

As against the normal flow of 4½ in. per hour in slow filtration, the rate in rapid filters frequently averages 160 in. to 180 in. per hour.

The Candy Filter. As stated above, in rapid filtration through sand or quartz for potable supply, artificial filming of the bed is essential, but in Chapter III we referred briefly to the bio-chemical properties of "Polarite" and

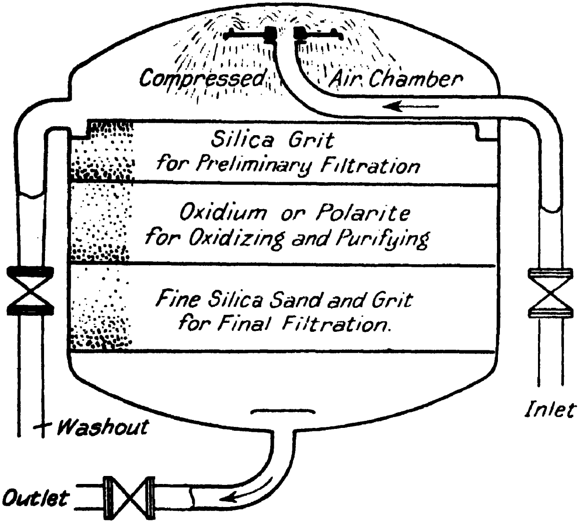
Compressed Air Chamber
Silica Grit for Preliminary Filtration
Oxidium or Polarite for Oxidizing and Purifying
Fine Silica Sand and Grit for Final Filtration.
Inlet
Washout
Outlet

FIG. 23.—CANDY PRESSURE FILTER.

"Oxidium." These artificial filtrants are used in the Candy filter (Fig. 23), which is very similar in external design to the Bell and Mather & Platt pressure filters shewn in Figs. 19 and 20. It has, however, no internal mechanical cleansing gear, but is divided into three cylindrical filter zones by horizontal perforated diaphragms. The upper zone is composed of coarse silica grit ; the middle zone is Oxidium or Polarite; and the lower zone has the usual graded bed with fine sharp sand at the surface. This, it will be noted is the reverse grading to the normal rapid filter, but bears some resemblance to the Puech-Chabal arrangement in slow filters.

In the Candy filter, filming is neither usual nor necessary. The domed cover is so constructed that, in filling after each cleaning period, a considerable volume of air is "locked" therein, prior to which the whole filter is emptied and air has free access to the Oxidium or Polarite to re-establish its activity. Cleaning of the bed, usually a daily occurrence, is effected simply by sending a reverse current of pre-filtered water forcefully through from below and allowing the mud and scum so released to escape to the drain. There is no mechanical agitation of the bed yet the filters are said to continue in good and workable condition for long periods.

The degree of organic and germ purification obtained with Candy filters, as vouched for after repeated tests by the most skilled experts we have, is second to that of no other type of filter, slow or rapid, but we believe that no one has claimed ability to explain fully the scientific reasons for this efficacy. There are several important installations, all of which we believe are satisfactory.

Sterilization by Ozone and Chlorine. Our outline of modern methods of purifying drinking water would be incomplete without allusion to Ozone and

Chlorine as germ-destroying agents. Oxone is described as an "allotropic variation of oxygen," a definition perhaps obscure to the average reader but rendered a little clearer by the analogy that charcoal and the diamond are allotropic variations of carbon. Ozone is produced by inducing a constant series of exceedingly high voltage electrical discharges in a current of dry air through which the water is afterwards allowed to percolate, either in open towers or in traversing a coarse filter bed. The germicidal effect appears to be very considerable and satisfactory in well devised installations, and particularly in that the system shows some selective action upon bacteria of the most deleterious nature. Several different types of plant of this nature have been installed, generally with good effect, but it would appear that experiments are as yet on an empirical basis and that the scientific side of the subject is but little understood.

The introduction of minute quantities of chlorine gas into water which has been previously well clarified by mechanical filtration is effective in neutralizing all dangerous germ contamination, and is probably to be regarded as one of the best safeguards against epidemics. The chief limitation is the difficulty of application so as to leave the water entirely tasteless and free from odour.

A most interesting and instructive account of the application of this system in field service during the war has been given by Captain J. Stanley Arthur, B.Sc.*

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* *Proc. Inst. Mech. Eng.*, Jan., 1921.

Testing of Potable Waters. *Clarity.* The initial and simplest tests to be made on a filtered water are those for clarity and colour. The first is generally made roughly at the filter station by two obvious devices—

(1) By collecting a sample in a clear glass tube of considerable diameter and looking through it;

(2) By lowering a white tile by means of a cord into a well and noting the depth attained before it becomes invisible.

A test on the lines of No. 2 is standardized for purposes of recording. Instead of the tile a piece of fine bright platinum wire is immersed in a vessel under conditions of constant illumination and the depth at which it becomes invisible is referred to a standard scale.

Colour. Perfectly pure water is not absolutely colourless but has a faint blue tinge. On the other hand, most natural waters (other than those from deep springs) have a more or less marked brown or yellow tinge. Several "colorimeters" have been devised for comparing samples, and most of them depend upon comparison with distilled water under standard conditions of lighting, through prepared coloured glass, or with the aid of standard solutions of colouring matter, for example cobalt or potassium bichromate.

Mineral Impurities. The hardness, acidity, and alkalinity of waters are readily tested with sufficient accuracy for general purposes by the well-known titration methods described in most chemical manuals, notably in Wanklyn's *Water Analysis.* Hardness is tested by titration with standard soap solution; acidity or alkalinity by standard alkaline or acid solutions with phenolphthalein or methyl-orange as indicators; and chlorine by standard silver nitrate solution with potassium chromate as indicator.

Organic Impurities. These are generally determined in terms of free and albumenoid ammonia by the Nessler test (which, in its final stage, is a very beautiful and accurate process of colour testing) against ammonia solutions of known strength, as clearly described in Wanklyn's *Water Analysis.* In skilled hands the determination of the "Oxygen Absorption" capacity—sometimes called the **moist combustion process**—is of value, as also is the estimation of nitrogen in oxidized form (Nitrites and Nitrates). The amount of oxygen absorbed is determined by adding to so much of the acidified water an excess of a standard solution of potassium permanganate, the liberated oxygen from which is capable of oxidizing—in part at least—the organic matter present. After allowing contact, usually for 3 hours at 64°F., the unattacked oxygen is estimated by a familiar volumetric titration process, and deducted from the original oxygen value of a "blank" experiment using distilled water.

Bacteriological Examination. It is now generally accepted that no water supply can be taken as safe for human consumption unless it is of a reasonable standard of bacterial purity. The enumeration of organisms is, of course, very necessary as showing filtration efficiency, but, in the strict hygienic sense and until comparatively recent years, too much importance has been attached to the number of colonies capable of growing in nutrient gelatine for a given period of time and under arbitrary conditions. Modern practice has shown that, in dealing with a potable supply, whilst due regard must be given to numerical "counts" in both gelatine (ordinary temperature) and agar-agar (blood-heat) cultures, and to the ratio which one growth bears to the other, the all-important tests are those which determine definitely the absence or presence of the organism indicative of excretal contamination, viz., the *Colon Bacillus.* MacConkey has placed in the hands of the bio-chemist a simple inoculation test for this organism which gives presumptive evidence of its presence on a quantitative basis.

A good general description of methods usually adopted in carrying out bacteriological examinations may be found in either Savage's *The Bacteriological Examination of Water Supplies* or Thresh's *Examination of Water and Water Supplies.* For a specification of the requirements from a first-class modern installation for public supply, the student is referred to a lucid paper read by the late Prof. Sheridan Delepine, appearing in the *Transactions of the Institution of Water Engineers*, Vol. XIX, 1914.

CHAPTER VI

CENTRIFUGAL AND VACUUM FILTRATION

During the last twenty years, the "centrifuge" or "whizzer" has become a most important machine in industry and its applications are ever extending. By a small effort of imagination almost all its applications may be regarded as filtration functions, even that in the laundry, the best known to the layman, where the machine may be conceived as a means of "sieving clothes out of water."

In filtration one may regard the centrifuge as the substitution of another and more readily controllable force, viz., centrifugal force, for the two forces hitherto mentioned (which are substantially one and the same), viz. gravity (or head) and pressure. In sieving or straining we supply liquid carrying matter in suspension to the strainer: all would descend under the action of gravity but the entrained matter is intercepted. In filtration involving the principles of sedimentation or flotation, as illustrated in Fig. 1, separation depends upon difference in specific gravity of liquids and solids. So also is the case in centrifugal separation, but the difference may be greatly accentuated, therefore the results may be correspondingly accelerated.

Calculation of Centrifugal Force. The formula for calculating centrifugal force is :

$$C = \frac{Wv^2}{gr}$$

where

C = centrifugal force in lbs.
W = weight of particle in lbs.
v = velocity in feet per second.
r = radius in feet from centre of rotation.
g = acceleration due to gravity
= 32·2 ft. per sec., at latitude of London.

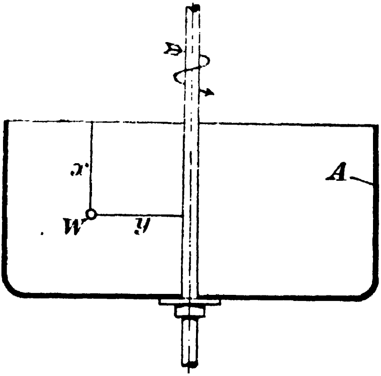

FIG. 24.—ILLUSTRATING ACTION OF CENTRIFUGE.

Assume now a particle W of very small weight within the cylinder A (Fig. 24), 1 ft. from the centre line of the shaft which is rotating at 3,000 r.p.m. In reality this particle would be floating in liquid which would itself have weight, but for simplicity of description we will assume that the cylinder is empty and that the particle is retained in its position by two weightless threads x and y. While the shaft is stationary the tension on $x = W$ and on $y = o$. When the shaft rotates, the tension on y is the centrifugal force.

The velocity v of W is given by :

$$v = 2\pi r \times \text{revs. per sec.} = 2 \times 3{\cdot}1416 \times 1 \times 3000/60$$
$$= 314 \text{ ft. per sec.}$$

and the centrifugal force on W is given by :

$$c = Wv^2/gr = W \times 314 \times 314/32{\cdot}2 \times 1$$
$$= 3060\,W$$

This is the tension in the thread y. In other words, the centrifugal force available to separate the particle from its vehicle radially is more than 3,000 times the gravitational force vertically available. An estimation on such simple lines as this is, of course, not practically applicable, in that the particle is not suspended by weightless threads but by a liquid which itself has weight, and the separating force is represented by the difference in density between the liquid and solid, or between two different liquids, such as milk and cream.

Centrifugal Separation by Straining. In simple straining or sieving under centrifugal action difference in density is of no moment. The centrifugal force acts just as would pressure over the filter beds previously described. Thus, referring to Fig. 25, assume that the revolving basket C, has a finely perforated periphery and is charged through the spout *D* from the evaporator of an ammonium sulphate plant. The crystals, too large to pass the perforations, are retained within the basket in substantially dry condition while the water finds its way through perforations to the spout *E*. If dealing with more finely suspended matter a filter cloth would be interposed at the periphery of the cage *C*.

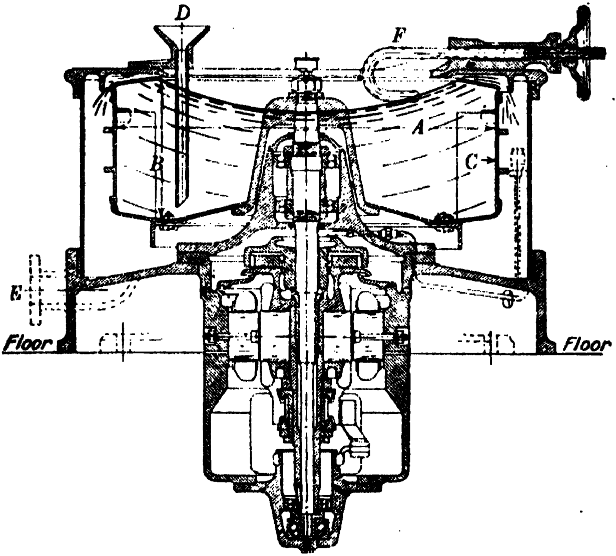

Fig. 25.—Electrically-driven Centrifuge with Skimming Arrangement.

(By Thos. Broadbent & Sons, Ltd., Huddersfield.)

Centrifugal Separation by Difference in Density. When the substance to be extracted is too fine for retention even by a closely woven cloth—when for example one has to deal with matter approaching the colloidal condition—the rotating cylinder is made with its walls unperforated, but is rotated at such high speed that the surface assumes a parabolic form as shown in Fig. 25. The lighter portions then spill over the edge into the outer casing or, in certain cases, will be caught and run off by the adjustable skimming device, *F*, the heavier solids having meanwhile, under centrifugal action, reached and adhered to the inner walls of the cylinder, whence they are removed during stoppages at frequent intervals.

Fig. 26 illustrates a small centrifuge for separating two liquids of different specific gravities and is in all essential features similar to the well known cream separator. The reader will be able to follow, from the notes above, how the heavier constituent, under centrifugal force, takes the outer course and, as the machine is charged down the central chamber, rises and finds exit by the lower spout. The lighter constituent rises to the higher level and is discharged from the upper spout. The fine annular deflecting discs shown are common to all such machines for purely liquid separation, and tend to increase efficiency by filming, interference, and probably by frictional adherence.

Speed and Effect of Centrifugal Separators. A paper read by Mr. F. J. Broadbent, M.Sc., at the Manchester College of Technology in December,

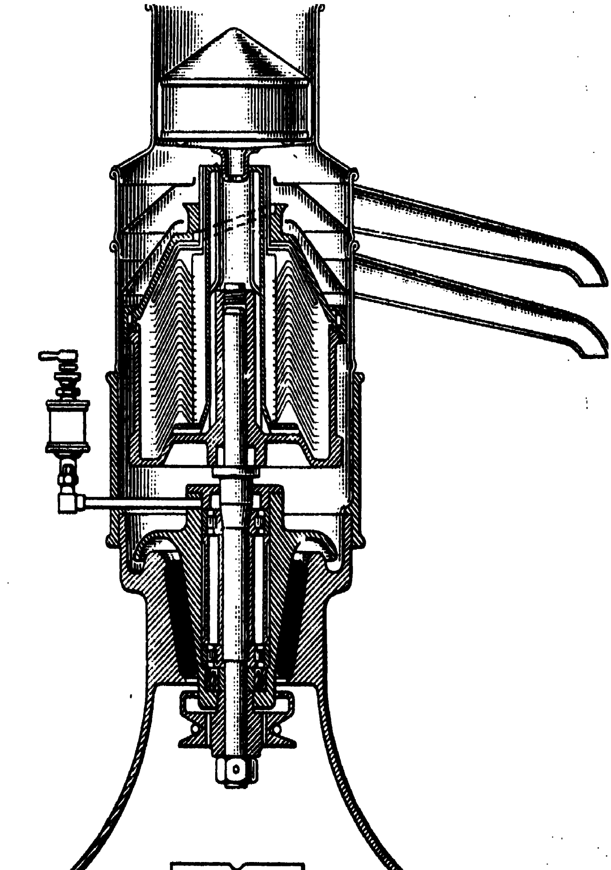

FIG. 26.—CENTRIFUGAL SEPARATOR FOR LIQUIDS OF DIFFERENT DENSITIES.

(By Watson, Laidlaw & Co., Ltd., Glasgow.)

1920, provides some very interesting notes upon centrifugal separation. The speeds at which centrifugal machines may be run with safety are determined by mechanical considerations; the stresses and vibrational effects which may arise despite careful design and workmanship are enormous, and, for factory use, impose limitations of speed which, to the theorist, appear regrettable. On this account, regarded only from the view point of "separation effect," small machines are more efficient than large ones. Table I is extracted from Mr. Broadbent's results for standard machines.

TABLE I

SPEED AND EFFECT OF CENTRIFUGAL SEPARATORS

Diameter of Cage.	Standard Speed.	Centrifugal effect in "Gravities."*
Ins.	R.P.M.	
9	2,200	618
18	1,500	575
30	1,150	561
42	1,000	596
72	650	431

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* These "gravities" are calculated on the bases shown on pp. 68, 69.

The paper proceeds to explain the results which would be possible under higher rotative speeds, and to describe efforts which have been and are being made in that direction, concluding with a short description of the Sharples Super-Centrifuge in which a 4 in. diameter drum is rotated at the enormous speed of 17,000 r.p.m., giving effect equal to 16,400 times gravity, while a still smaller machine, with 2 in. diameter drum running at 40,000 r.p.m. exercises a separating effect equal to 45,000 times gravity. The author continues—

"It is claimed, with apparent justification, that these are the highest values of centrifugal force used in practice. The care required to balance such machines and to allow flexibility of swing will be readily appreciated. With the smaller machine it is stated that sub-microscopic particles can be removed and such difficult separations as that of serum from blood can be efficiently performed. The passages through which the liquids flow are necessarily small in machines of this type and with even very small quantities of certain kinds of solids these passages soon choke. In such cases a very excellent plan, which has been patented by a firm in this country, is to use a much larger imperforate hydro-extractor first as a roughing machine. This will remove a considerable quantity of fine solid particles and also part of the liquid to be recovered and the remaining liquid is then treated in the Sharples super-machine. In this way it was found that instead of cleaning the Sharples bowl every hour it was only necessary to clean every 24 hours and although it is not a difficult matter to do this and a spare bowl can be re-fitted in five minutes, yet in the case mentioned the two machines made all the difference between a commercial success and a commercial failure."

Laboratory Centrifugals. Before leaving the subject of centrifugal separation we may refer briefly to its use in the laboratory, by reference to Fig. 27, as illustrating to the general reader the wide utility of the principle. This illustration represents the central vertical spindle of a machine carrying a specially shaped disc which is prepared to receive ten or twelve graduated test tubes. A mixture, let us say new milk, or mineral oil carrying paraffin wax, is put into the test tubes and the spindle is rotated by simple gear at a speed of about 2,000 r.p.m. The heavier ingredient is forced outwards radially and the proportion of the lighter ingredient is shown volumetrically by direct reading on the scale, as a percentage of the whole.

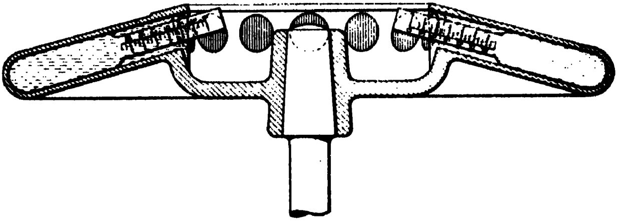

FIG. 27.—LABORATORY CENTRIFUGAL FOR DETERMINATION OF LIGHT AND HEAVY INGREDIENTS IN SAMPLES OF MIXTURES.

(By Watson Laidlaw & Co., Ltd., Glasgow.)

Vacuum Filtration. In ordinary vacuum filtration there is no important variation from the procedure previously described of filtration at atmospheric pressure under "head." The speed of filtration through a given bed is proportional to the *difference* in pressure or head over and below the medium, and when it is not practicable to obtain sufficient pressure on the inlet side, like effect may be obtained by exhausting or setting up negative pressure on the discharge side. Generally therefore the substitution of vacuum for pressure filtration in industry is determined by conditions of mechanical convenience. We should describe, however, one type of apparatus which works under vacuum for continuous filtration and which, although old in principle, has recently met with extended favour in many chemical processes. This machine is illustrated diagrammatically in Fig. 28 and is preferred to centrifuging or like alternatives mainly because it is continuous in action. The drum *A*, which has a perforate periphery but solid ends, is covered by filter cloth, and rotates slowly in the bath *B*, into which the liquor to be filtered runs continuously. The internal pipe *C* passes out through one of the hollow bearings or trunnions where it is fitted with an air-tight stuffing box, and communicates with the receiver *D*. This in turn can be exhausted continuously through the pipe *E*, connected to a vacuum pump, and can be emptied of liquid through the cock *F* and the long barometric pipe *G*.

When the apparatus is worked, the negative pressure in the drum *A* induces the liquor through the cloth, the suspended matter being strained out and remaining caked upon the outside. The clear liquor is drawn to the receiver *D*, whence it may be discharged at intervals by hand manipulation of the cock *F*, or by one or other of the many well-known automatic devices for this purpose. The mud on the cloth is cleared away continuously by the scraper or " doctor " blade *H*, and falls in to a suitable receptacle or on to a conveyor.

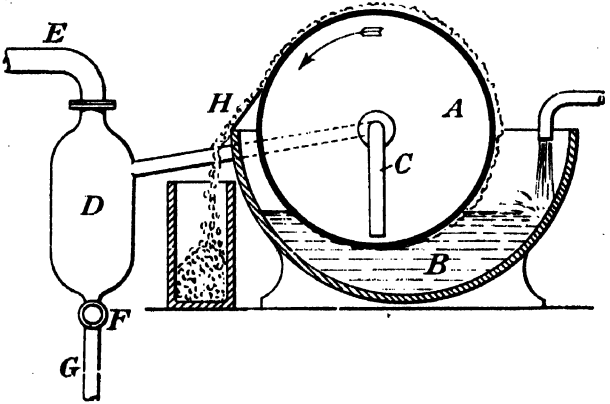

FIG. 28.—ILLUSTRATING CONTINUOUS FILTRATION UNDER VACUUM.

This apparatus is most commonly used when both the clear liquid and the extracted mud are valuable products.

The American " Oliver " vacuum filter, and similar devices apparently inspired thereby, are, in their simplest form, like the diagram Fig. 28, but have been elaborated and are meeting with greatly increased favour for many " Chemical works" processes as substitutes for the ordinary plate filter press. The preference rises chiefly out of the fact that the operation of vacuum filters is continuous and therefore output is increased and labour reduced. In the normal filter press, the cake may be washed with water or solvent liquor *in situ* and before removal (p. 26). In the Oliver vacuum filter, provision is made for such washing, without interrupting continuity of working, by dividing the periphery of the drum into longitudinal box sections, each communicating with a central automatic valve box by a radial pipe. The cake is deposited upon the cloth during an early portion of angular motion, and during a later portion of the revolution, but before the cake reaches the "doctor," water or other solvent is sprayed upon it from outside. This is sucked through, abstracting from the cake and carrying forward all residual soluble matter, and the weak liquor is discharged separately and independently from the original strong liquor.

CHAPTER VII

FILTRATION AND CLARIFICATION OF OIL

IN Chapter IV we have, in dealing with industrial filtration generally, alluded to apparatus of the nature used in the manufacture of animal, vegetable, and mineral oils, and we propose, in the first instance, to touch a little more in detail upon the methods of application of these, for example the oil press, the filter press, and the charcoal filter. It is not easy to do so without wandering to some extent from our real subject—filtration—as other chemical and physical functions are so closely associated therewith. Further, there are so many varieties of oil, so many sources, and so many ideas peculiar to the localities of production, that the present notes must be of the most general and brief nature.

Vegetable Oils. These are chiefly derived from seeds, rape, linseed, cotton, and the like, by crushing and pressing. The seed is first ground or crushed to break up the oil-cells and to facilitate expression. Following a moderate heating process, it is transferred to the oil press and subjected to intense mechanical or hydraulic pressure whereby the oil is squeezed out and flows away to tanks, the seeds being retained as "cakes" and largely used for cattle feeding. A plant for crushing and pressing seeds is illustrated in Fig. 10, but there are many varieties. In some presses the crushed seeds are packed in cloth bags and pressed between flat plates, when the bags act as filters. Sometimes the seeds, after being pressed for the best oils in the above manner, are further treated with solvents such as benzol, petroleum spirit, or carbon di-sulphide, in closed vessels, either by hot or cold process. The solvent absorbs the last traces of oil from the seeds, and the liquor is afterwards distilled, the oil being retained in the still and the volatile absorbent condensed for use over again.

Animal Oils. On broad physical lines the same procedure is adopted in producing animal oils as with vegetable oils but the apparatus used is very different. The fatty portions from the slaughter-house are minced and put with water into a closed vessel or jacket pan where they are boiled by steam for some hours, and then allowed to settle. The clear oil rises to the surface and is removed by decantation. The residue is frequently treated with a small amount of sulphuric acid and pressed for the last obtainable traces of poorer quality oil.

Mineral Oils. The volatile and fluid products of mineral crude oil or oil-shales are distillates and do not therefore, in their commercial qualities, call for much filtration. The more viscous products, manufactured chiefly from the residue left in the stills after distillation, do call for very careful filtration, particularly those fine amber coloured cylinder oils, which are very carefully filtered through animal charcoal or fuller's earth.

Filtration is an important item in the separation of paraffin wax from mineral oils which are first subjected to refrigeration, to solidify the wax, and then passed through the filter press.

Filtration of Old Oil. Oil which has been used for lubrication becomes dark in colour and is invariably contaminated by dirt and metallic particles. Some authorities argue that if these are removed the oil loses none of its lubricating value. Whilst the author cannot wholly endorse this view, it is beyond question that great savings may be effected in large works by purifying the oil recovered from lubricating systems. Prolonged storage of such oil in tanks, maintained at a temperature of about 140°F. by steam coils, goes a long way towards rendering the oil suitable for re-use, although this simple procedure does little or nothing towards bringing back the original colour and clarity.

Fig. 29 illustrates the Wells oil filter, one of many designs of similar type. The use of one or other of these filters has become practically universal in factories of any size. The filter illustrated comprises three cylindrical chambers which are superposed and fit into one another so that, by simply lifting them apart, all internal portions are accessible for overhaul and cleaning.

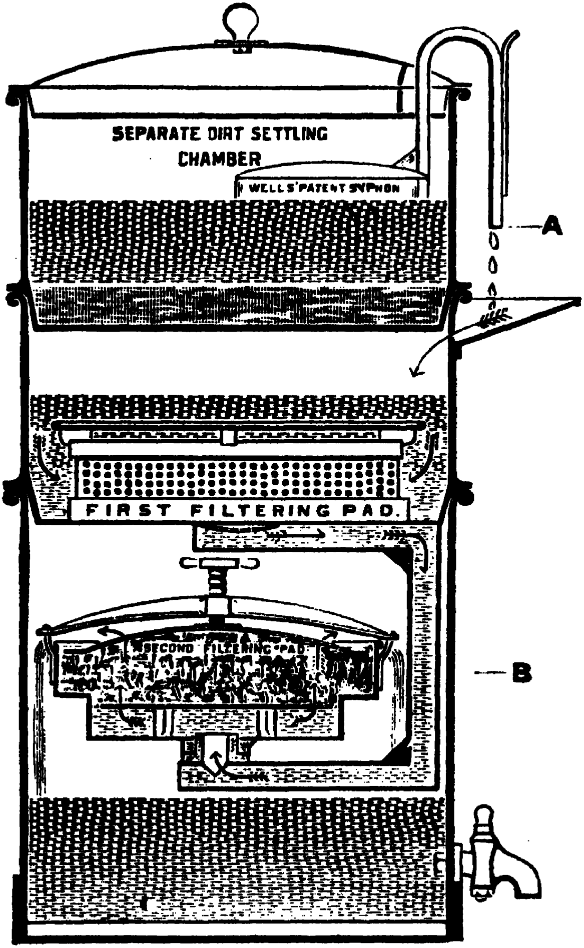

FIG. 29.—WELLS WASTE-OIL FILTER.
(By A. C. Wells & Co., Manchester.)

The top chamber, into which dirty oil is poured as available, provides simply for sedimentation, and is sometimes fitted with a small steam coil (not shown in the illustration) whereby the temperature may be maintained at about 150°F. As explained in connection with the Wanklyn subsidence filter (Chapter II), the top film of oil clears first and the patent floating syphon shown is devised so that all oil transferred to the second chamber is drawn from the surface. In the second chamber the oil passes radially inwards through perforations in a filter box containing pads of somewhat loosely woven fabric, and is freed from suspended matter of any considerable magnitude. The pre-filtered oil then passes to the underside of the filter box in the lowest chamber under a head averaging about 12 in. By upward filtration through a series of fabric pads suitably clamped down, the oil is relieved of all the fine suspended matter not removed by the pre-filter. The space below the lower filter box acts as storage from which the clean oil may be drawn as desired. The construction of the second filter box is ingenious, providing first that there shall be no short circuiting of the oil past the edges of the pads, and secondly that the degree of compression of the pads may be regulated in accordance with the fluidity or viscosity of the oil.

A system of waste oil filtration, recently placed upon the market by the British Thomson Houston Co., Ltd. (Rugby), should be mentioned here. No claim can be made for it as embodying invention or new principle but, for large power installations, it is compact, handy, and obviously efficient. It has origin in the necessity for de-hydration and purity of the oil used in large electrical transformers at power stations,* but is equally efficient in dealing with lubricating or any other fluid oils. It comprises a small horizontal filter press almost exactly, in miniature, like the press shown in Fig. 8 (p. 24). This is mounted in self-contained form over an electrically-driven, high-duty centrifugal pump. The combination is placed in circuit with a storage tank of considerable size into which oil collected after use is run. Circulation is continuous to and from this tank through the press, and thus a high degree of straining is constantly maintained. Instead of the usual fabric as filtering medium ordinary blotting paper is used, clearly an ideal medium as regards straining properties, but, as clearly, very fragile when in its moistened condition; the fact that it may, in several thicknesses in the press, be subjected to pressures of 100 lb. per sq. in. is testimony to the perfection of design and construction of the plates.

As previously stated, simple straining of this nature will not return the oil to its original condition of colour and clarity, but on the other hand it will remove all matter likely to have deleterious effects upon even the finest machinery and it will restore partially, if not wholly, the lubricative value, provided that the oil was suitably compounded in the first instance. Oils compounded from vegetable bases of oxidizable nature, such as cotton-seed, resin, and the like are not desirable to start with, and are certainly unsuitable for re-use after filtration.

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* See also *High Voltage Power Transformers,* by W. T. Taylor, uniform with this volume (Pitman, 2s. 6d. net).

Clarifying Oil. Clarity and colour are of importance commercially if not technically in oil refining. These qualities are usually obtained by chemical means, for example by intimately mixing sulphuric acid or caustic soda with oils, subsequently washing thoroughly with water to remove the last traces of acidity or alkalinity (as the case may be) and decanting.

A method of clarifying frequently used, which may be regarded as physical rather than chemical, is to mix intimately with the discoloured oil mineral substances in finely divided form, fuller's earth being perhaps the substance most commonly used, and then to separate by cloth filtration in a filter press or by the use of a centrifuge. The effect of this procedure may aptly be compared with that of coagulation in purifying greasy water as described in Chapter I. The finely divided mineral particles attract and attach themselves to the matter causing discolouration and, being removed by filtration, leave the oil bright and clear.

Spun-glass Filters. While engaged upon this work the author's attention has been directed to the success attained in oil filtration by using bundles of finely spun glass loosely packed in an enlarged portion of the pipe through which the oil is passing. Screens of this material were utilized several years ago and found to be very effective in extracting the last traces of tar and moisture from gas, but the application for oil filtration appears to be quite new. So far as entrained solids, sand, and the like are concerned, it is not easy to understand wherein the stated efficiency lies, for although, regarded as a mesh, the interference may be very marked, the smooth nature of the surface of spun glass is comparable to the billiard balls of Fig. 3 rather than to the coke bed of Fig. 4. On the other hand the efficiency claimed as regards de-hydration, the agglomeration of minute water particles in oil into fewer large masses capable of subsequent separation by settlement and decantation, is readily comprehensible. Developments of this discovery are likely to be interesting.

CHAPTER VIII

FILTRATION OF AIR

Evils of Atmospheric Pollution. By a happy coincidence, when on the point of commencing work upon this chapter, the author found in *The Observer* a column from which is taken the following powerful testimony to the evils of atmospheric pollution—

"When Pittsburgh was inquiring into this matter, prior to the great clean-up which I described here in the autumn after witnessing its results—and which I remember the more vividly when inhaling the dirt and cowering under the darkness of our own steel metropolis—the authorities paid particular attention to psychology, and the result is to be found in their Bulletin No. 3, 'Psychological Aspects of the Problem of Atmospheric Smoke Pollution,' by Dr. Wallace Wallin, Director of Psychological Clinic, University of Pittsburgh. This is a very fine and complete piece of work, fully documented, and now very scarce, and I only wish I knew how it could be widely distributed in our country. At least I may here quote from the 'Summary of Conclusions,' premising that in the text itself good and exact evidence from many competent observers is cited for findings which, by themselves, may appear too dogmatic in form:

"The mental effects of smoke and smoke-produced weather states are direct and indirect. The indirect effects issue from bodily changes thus produced, while the direct effects are due to the influence of the mind's own states upon its subsequent thoughts, disposition, and conduct.

"Smoke fills the atmosphere with acrid, poisonous compounds and soot particles which . . . diminish the potential reserve, working capacity, and well-being of the individual, increase fatigue, irritability, and malcontent, and may tend to hasten premature decay.

"Smoke clouds are inimical to the highest aesthetic development of urban communities. They seriously limit not only the possibilities of Municipal art, in respect to architecture, statuary, painting, and ornamental gardening, but also limit the possibilities of art education in the community in question. . . . . They befoul the persons as well as the dress of the inhabitants, limit the range of wearing apparel, and may foster habits of indifference. They obliterate the natural panorama of art, the iridescent clouds or the sky.

"Our knowledge of the mental influences of atmospheric smoke pollution should be rendered more complete by systematic psychological research." (*The Observer*, April 3rd, 1921).

Filtration Requirements for Ventilating Buildings. Beyond all question attention to the purification of air in ventilating public buildings, particularly in industrial districts, is of primary importance, as anyone may gather by observing walls and ceilings in the neighbourhood of air inlet ducts, above gas jets, or in any position in which, by reason of induced currents, constant baffling occurs. Everyone knows something of the amount of dust carried by the atmosphere as visible in a darkened room penetrated by a ray of sunlight. Some specialists state that air filtration should be carried out so carefully as to intercept air-borne germs of all kinds, but the majority of ventilating engineers do not go so far, arguing that, in the worst instances, germ contamination of the atmosphere of a building due to limitations of the ventilating system, is insignificant as compared with like contamination due to the inmates, and that all that is necessary is to intercept such mineral and organic matter in suspension as may broadly be designated "dust."

Mechanical ventilation of large buildings, that is to say the positive injection of fresh air into—or extraction of foul air from—them by fans is now almost universal. The former, known as the "plenum" system, has many advocates and certainly lends itself to air purification better than the latter in that it determines that practically all fresh air supplied shall pass through the apparatus designed for its filtration. It is no part of our duty to discuss here the merits and demerits of the various systems of ventilation, but only to deal with methods adopted for air filtration where such are practicable.

Dry Air-Filters. Though "washing" the air by water is an essential feature of most systems, something may be said about the dry system, that is to say drawing or forcing the inlet air through fine mesh screens or, more generally, fine muslin. In one case within the author's knowledge, air is supplied to a large building by an enclosed fan blowing into a main duct, from which branch ducts lead to various rooms. Arrangements are made whereby a long sausage-shaped muslin bag can be affixed to the fan discharge orifice so as to blow out into the main duct, and to catch any particles too large to pass the interstices of the weave. We have no record of the percentage purification obtained by this means, but, if the filthy condition of the bags after a few hours run may be taken as an indication, they are doing very good service. Spare bags are kept, so that, when one is fouled, it is removed for washing and replaced by a clean one.

Messrs. James Keith & Blackman Co., Ltd., have fitted a type of dry filter which is said to give good results and is interesting in its resemblance to the devices for rough water-filtering illustrated by Figs. 5, 6, and 7 *ante.* Their drawing, kindly lent for descriptive purposes, shows a chamber the cross-sectional area of which is twenty-five times that of the fan discharge pipe which blows into it. Within this chamber are six filter frames, each of approximately the same cross-sectional area as the chamber but mounted zig-zag, like the letter W, so that the total area presented is 150 times that of the fan discharge, and the air velocity through the frames is reduced in like proportion. Each frame is made of two thicknesses of wire mesh about 2 in. apart, the space between them being loosely packed with cotton wool. Spare frames are supplied so that, when those at work become choked, they may be removed for re-packing and the spares put in their place.

Wet Air-Filters. As stated previously, water in the form of fine sprays or films is the chief medium employed for the cleansing of air. The mere passing of air through a chamber all parts of which are reached by fine water-sprays, the formation one may say of a miniature rain-storm, is effective in removing as much as 98% of the total entrained impurity comprising smoke residue, road dust, and the like, from city air. In other apparatus closely-spaced timber or metallic baffles, louvres, or the like are placed in the air duct and films of water are equally and constantly distributed over their surfaces. The dust particles adhere to the wetted surfaces and are automatically washed down.

Still another and once very popular form of air filter consisted of a screen of cocoa-matting or other fabric stretched across the air duct and maintained in wet condition either by jets of water playing upon it or by causing the screen itself to pass over rollers through a bath of water. The "coke scrubber" used in connection with nearly every suction gas plant for removing coal and ash dust from gas previous to its entry to the gas engine cylinder is substantially similar in operation. Though continuously-moistened mat or fabric screens of various patterns have been used extensively as air filters, the general consensus of opinion is that it is hard to prevent accumulations of filth round about the carrying mechanism, and that carelessness or neglect may lead to conditions of incidental air contamination worse than if no attempt at filtration were made.

Water-Spray and Wet-Surface Filters. We may with advantage describe one of many air filters standardized by British firms as typical of the best. It comprises a chamber of such cross section that the velocity of the incoming air averages about 600 ft. per min. This chamber is open to the outside air at the inlet end and the fan at the opposite end draws fresh air through it. The base is constructed as a tank to hold water and this is maintained at a constant level by means of a ball valve. At the entrance end are several nozzles capable of sending forcefully very finely divided sprays of water forward in the same direction as the air is travelling, but at much higher velocity. These nozzles are generally fed by a small motor-driven centrifugal pump drawing water from the tank base, and a fine sieve is inserted in the suction pipe to intercept any dirt, the result of earlier circulation, which might tend to choke the spraying nozzles. At the fan end are mounted vertically two sets of plates or louvres closely spaced and set at an angle to the normal direction to the air flow so as to have a baffling effect without setting up undue resistance. The first set of plates are maintained in flooded condition by streams of water also derived from the aforementioned centrifugal pump. The second set of plates, set at the reverse angle, may be regarded as dryers and are fitted with edges turned back or lipped to intercept any unabsorbed particles of water carried forward by the air current. Following the dryer plates the chamber tapers away gradually to the fan inlet.

The principle of operation is that most of the dust particles, when saturated with water, are heavy enough to fall out of the air current by their own weight. Those which are carried on strike and momentarily adhere to the first set of baffle plates but are soon washed down into the tank by the flooding water.

It is usual to fit a glazed door to such air filters and to mount an electric light within them, so that inspection while running, particularly to note that the spraying nozzles are functioning, is easy. Ready facilities are provided for periodic cleaning out of the accumulated dirt.

The apparatus above described is manufactured by Messrs. Davidson & Co., Ltd., of Belfast. A very similar arrangement i fitted by Messrs. James Keith & Blackman Co., Ltd., and other arrangements, often with flooded cloths substituted for louvres or baffle plates, but generally embodying similar principles, are devised by well-known ventilating specialists.

Messrs. Musgrave & Co., of Belfast, have devised and fitted in connection with many ventilating systems a very simple air filter which is in principle and effect somewhat similar to those described above, and is said to be very economical as regards running and upkeep. The distinguishing feature is the substitution, for multiple spraying nozzles fed by a pump, of a small power-operated paddle-wheel which rotates at high speed within the enlarged inlet duct. A small stream of clean water is allowed to fall continuously upon this wheel with the result that it is dispersed centrifugally as an atomized water screen right across the chamber, through which screen all air must pass.

Humidity of Wet-Filtered Air. One of the difficulties associated with wet filtration processes for air is that of attaining simultaneously a suitable temperature and a suitable degree of saturation. Following filtration, with most installations on the plenum system, the air is heated by passing through a battery of steam pipes. Air will absorb a certain amount of moisture and its capacity for moisture increases with every rise of temperature. For comfort of those inhaling it a moderate and correct percentage of saturation should be maintained. The weight of water which 1 cu. ft. of air will absorb to become saturated at various temperatures is shown by the graph, Fig. 30. It will be evident that, in passing through a wet filter of the type described above, complete saturation is not only possible but probable. This difficulty can be overcome fairly well during cold weather. Thus suppose air is drawn through the filter at 30°F. and leaves in a saturated condition, i.e. carrying 2 grains of moisture per cu. ft. If the air be raised to 60°F. in the heater, it is

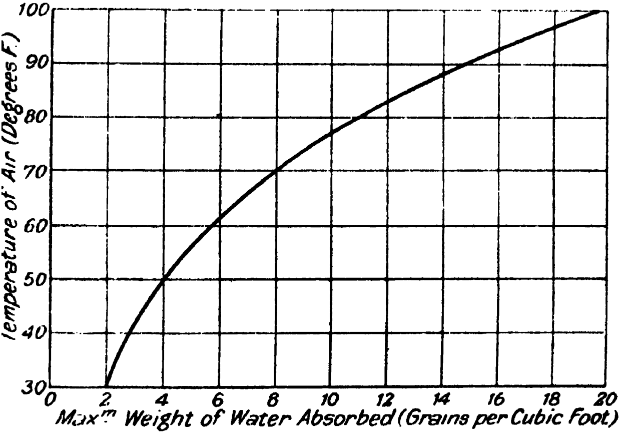

FIG. 30.—WATER ABSORBED BY AIR AT VARIOUS TEMPERATURES FOR SATURATION.

then capable of carrying about 5·8 grains of water per cu. ft. (*see* Fig. 30) so that the actual percentage saturation would be:

$$100 \times 2/5{\cdot}8 = 35\% \text{ (approx.)}$$

which is a comfortable degree for respiration.

Electrostatic Precipitation. We should not conclude this chapter without reference to the separation of dust and moisture from air and other gases by electrical means. From the practical standpoint this subject is still in its infancy, but a very large amount of research work has been done in this country and abroad. Quite a number of large-scale plants are, even now, successfully at work, of which perhaps the largest is that at the Portland Cement Works, near Riverside, California, which deposits over a hundred tons of dust daily from the gases of rotary cement kilns. There is little doubt that in the near future the principle will be largely adopted for industrial and public-welfare applications.

It has been known for almost a century that if a suitable electrical discharge takes place within a vessel containing smoke the cloudy appearance disappears almost instantly and the components of the smoke are deposited upon the walls of the vessel. It has been suggested that violent rain and hail storms following a flash of lightning have a similar origin. Sir Oliver Lodge pursued the subject to a considerable extent thirty years ago and in most interesting directions: primarily, as a means of recovering valuable by-products existing as dust in the fumes generated in metallurgical processes, and, secondly, as a means of dissipating fog. The last mentioned is, of course, a heroic ideal, but may, in the opinion of more than one experimenter, have interesting developments.

The researches of Sir Joseph J. Thomson and the late Sir William Crookes, and the experimental work carried out by Dr. F. G. Cottrell in America, have made clear the underlying principles of electrical precipitation. If two electrodes be connected to a source of rectified high-tension supply, atoms of negative electricity, called electrons, flow from the negative electrode. The electrons move at a great speed and collide with, and become attached to, the molecules of the surrounding gases and also to any dust or smoke particles that may be present. In this way the particles become electrified and tend to move towards the positive electrode under the influence of electrostatic attraction, just as small pieces of paper tend to fly to an ebonite rod electrified by rubbing. The velocity imparted to the particles by this electrostatic attraction, however, is not great, and the essential requirement for the precipitation of the particles is for the negative electrode to be relatively small and the positive electrode to be relatively large, so that an intense electric field is created which, acting upon the electrified particles, drives them to the positive electrode with considerable force.

The apparatus generally used up to the present time consists of elements, each of which is in the form of a high vertical iron or steel tube of comparatively small diameter, provided at its base with a dust-collecting chamber common to a number of elements. A suitably insulated bare wire is mounted concentrically within each element. These wires are connected to the negative terminal of a current rectifier supplied from a transformer, and the tubes are connected to the positive terminal. A sufficient voltage has to be supplied to cause what is known as a corona discharge from the wires, and, obviously, it varies with the diameter of the tubes employed. Pressures as high as 250,000 volts have already been employed, but for small plants from 30,000 to 50,000 volts is more usual. The air or other gas to be treated flows up the tubes, and the velocity must be kept within a certain critical value to enable the precipitation to have full effect. Under the influence of the electric field the electrified particles are driven violently against the interior walls of the tubes, where they coalesce and fall inert into the dust chamber below. Although the voltage used is so high, the energy consumption is not so large as to be likely to prohibit the general use of the system on account of cost. In more than one instance, where the system has been adopted chiefly as a means of preventing contamination of the surrounding atmosphere by dust, the collection of this dust (potash, for example) alone shows a good rebate upon the operating costs. In other cases where the dust rises from the smelting of valuable ores the gain has been considerable. The visible effect is most marked. One sees dense fumes rising from a chimney or duct; the current is switched on to the apparatus and in some fraction of a second the fume column is cut off as if by a knife.

We are not aware of the installation of this system in connection with the ventilation of buildings in this country up to the present, but it would appear to be within the range of early possibility.

Those interested in the subject will find elaborate papers dealing with it historically, mathematically, and practically by Messrs. Cottrell, Strong, Nesbit and Bradley, appearing in Vol. XXXIV, Part I, of the *Transactions of the American Institute of Electrical Engineers.*

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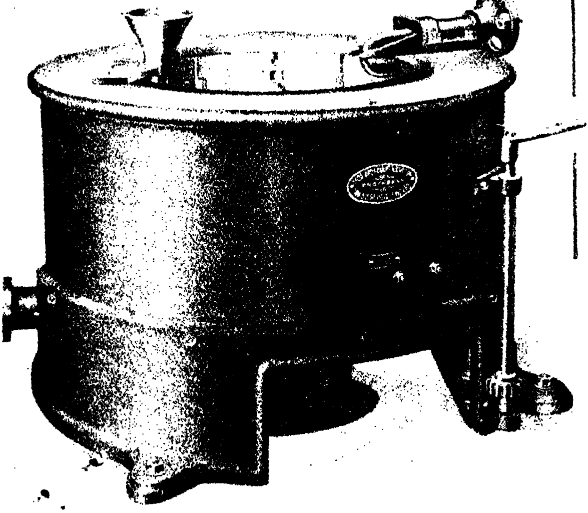

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